The Internal Processes

Chapter 14

Rigid Earth to Plate Tectonics

- **Wegener's Continental Drift Theory**
  - **Developed during the 1910's and 1920's**
  - Supported by the **jig-saw puzzle way South America and Africa went together**
  - **Mountain belts of Greenland, Scandinavia, British Islands and the Appalachian Mountains all match up**
  - **Dinosaur species in Africa and South America matched up**
  - **Plant Fossils matched in Africa and South America, where seeds would not be able to cross the ocean**

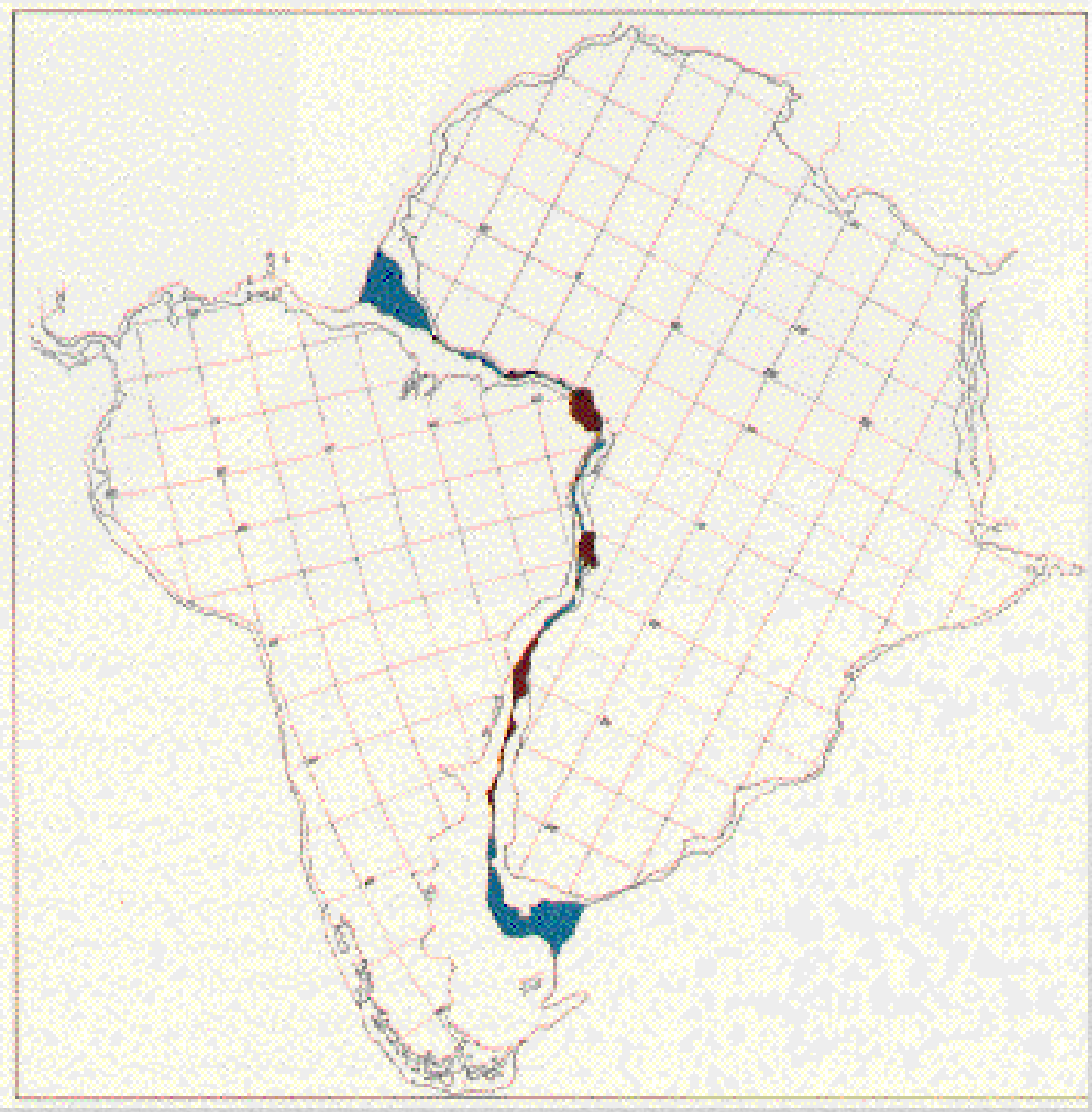


Plate Tectonics

- **Accepted by the 1950's**
  - Supported by depth soundings
  - Found seamounts/ridges or trenches
- **Seafloor spreading**
  - **1960's new theory- by Harry Hess and Robert Dietz**
  - **Mechanism for continental drift, mid ocean ridges form from rising mantle creating ridges, spreading the ocean floor**
  - **Verified by the paleo-magnetism—reversal of pole magnetism**
  - **New crust is formed and returned to the mantle every 200 million years**

57cd_SeaSpread_SP.swf

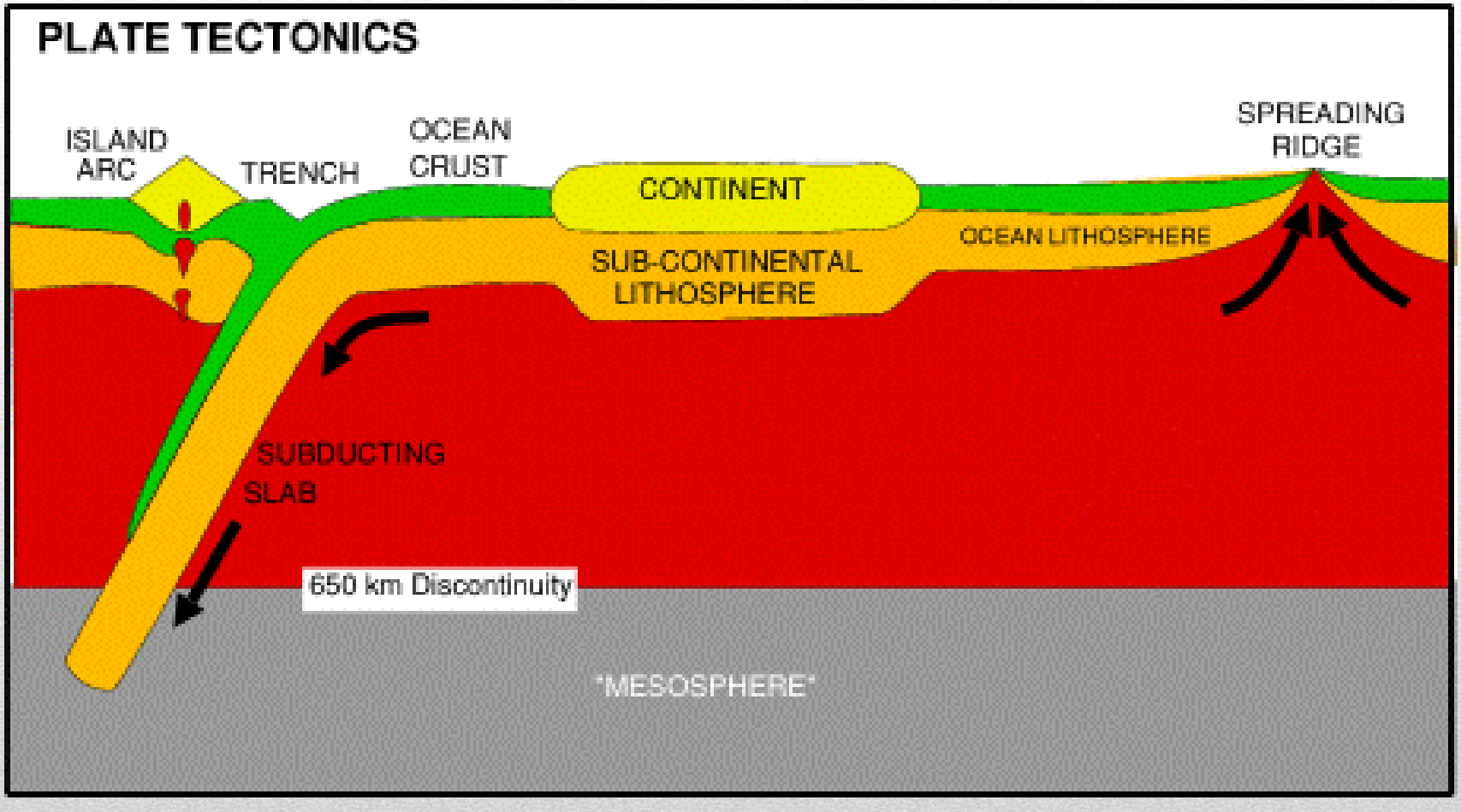


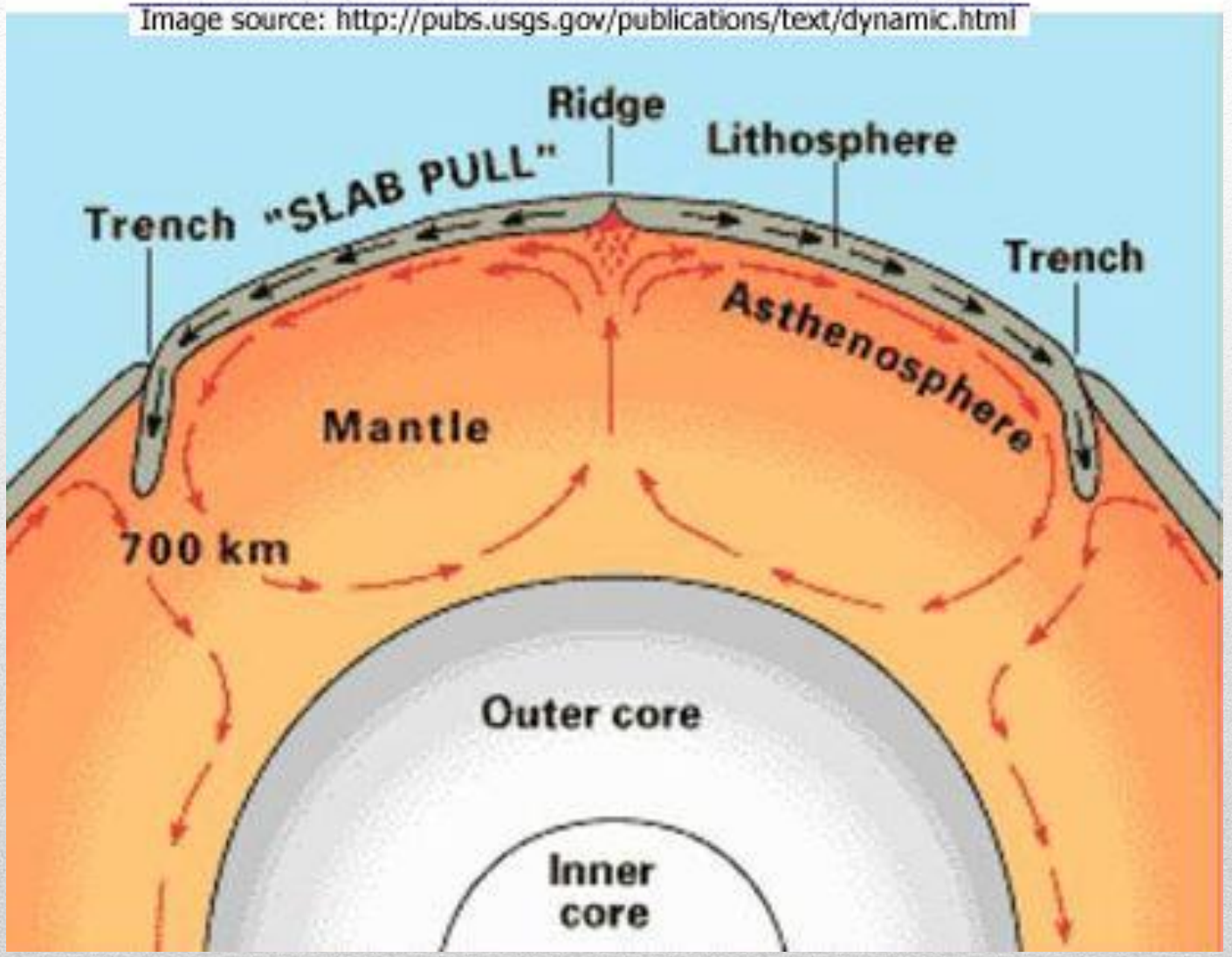
PLATE TECTONICS
ISLAND ARC
TRENCH
OCEAN CRUST
CONTINENT
SPREADING RIDGE
OCEAN LITHOSPHERE
SUB-CONTINENTAL LITHOSPHERE
SUBDUCTING SLAB
650 km Discontinuity
"MESOSPHERE"

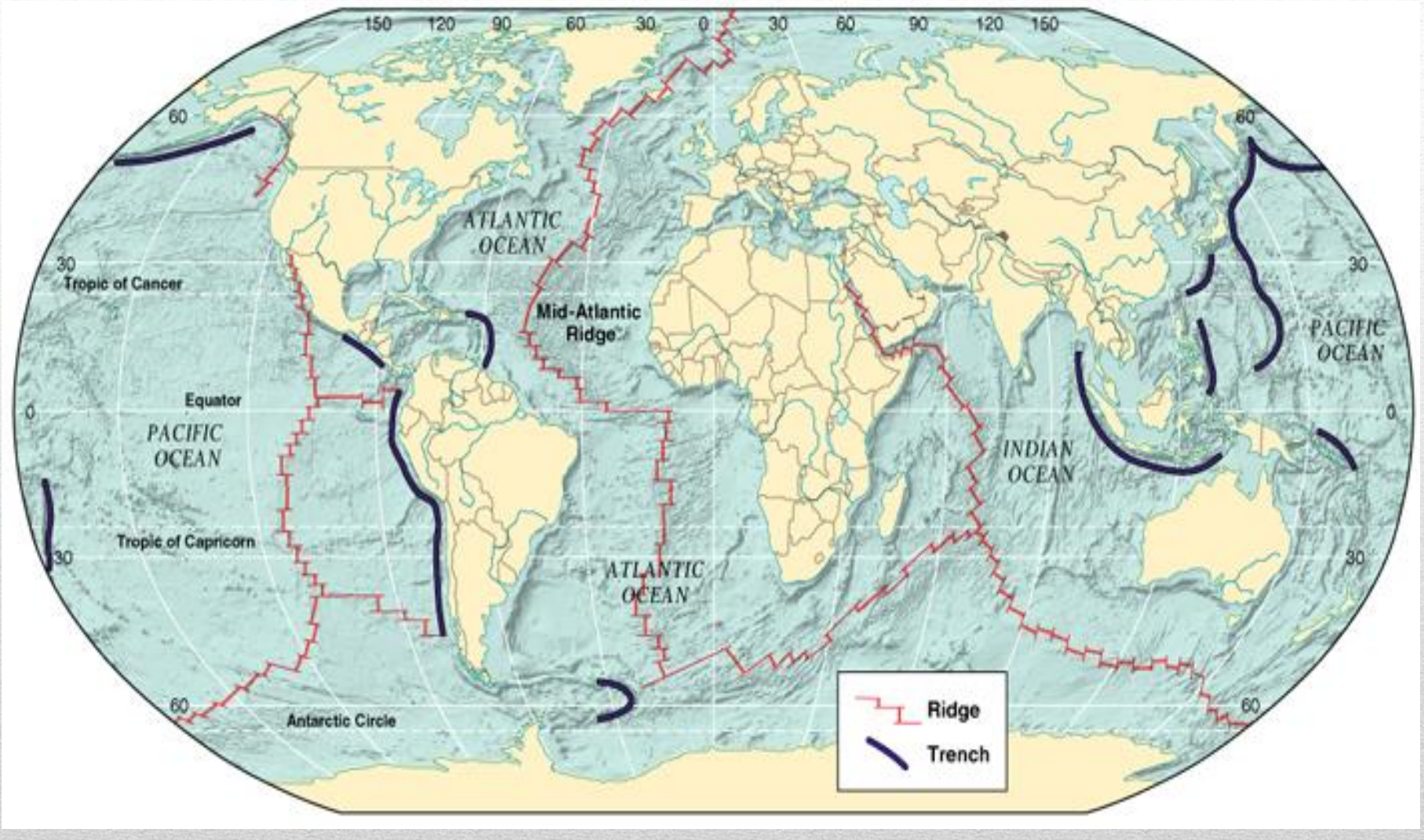
Plate Tectonics

- **By 1968- plate tectonics widely accepted by a scientific community**
- **The lithosphere is a mosaic of rigid plates floating over the underlying plastic asthenosphere**
- **Convection is driving mechanism within the Earth's mantle**

The Forces That Cause Plate Tectonics

Image source: http://pubs.usgs.gov/publications/text/dynamic.html




150
120
90
60
30
0
30
60
90
120
150
60
30
0
30
60
ATLANTIC OCEAN
Mid-Atlantic Ridge
Tropic of Cancer
Equator
PACIFIC OCEAN
Tropic of Capricorn
ATLANTIC OCEAN
INDIAN OCEAN
PACIFIC OCEAN
Antarctic Circle
Ridge
Trench

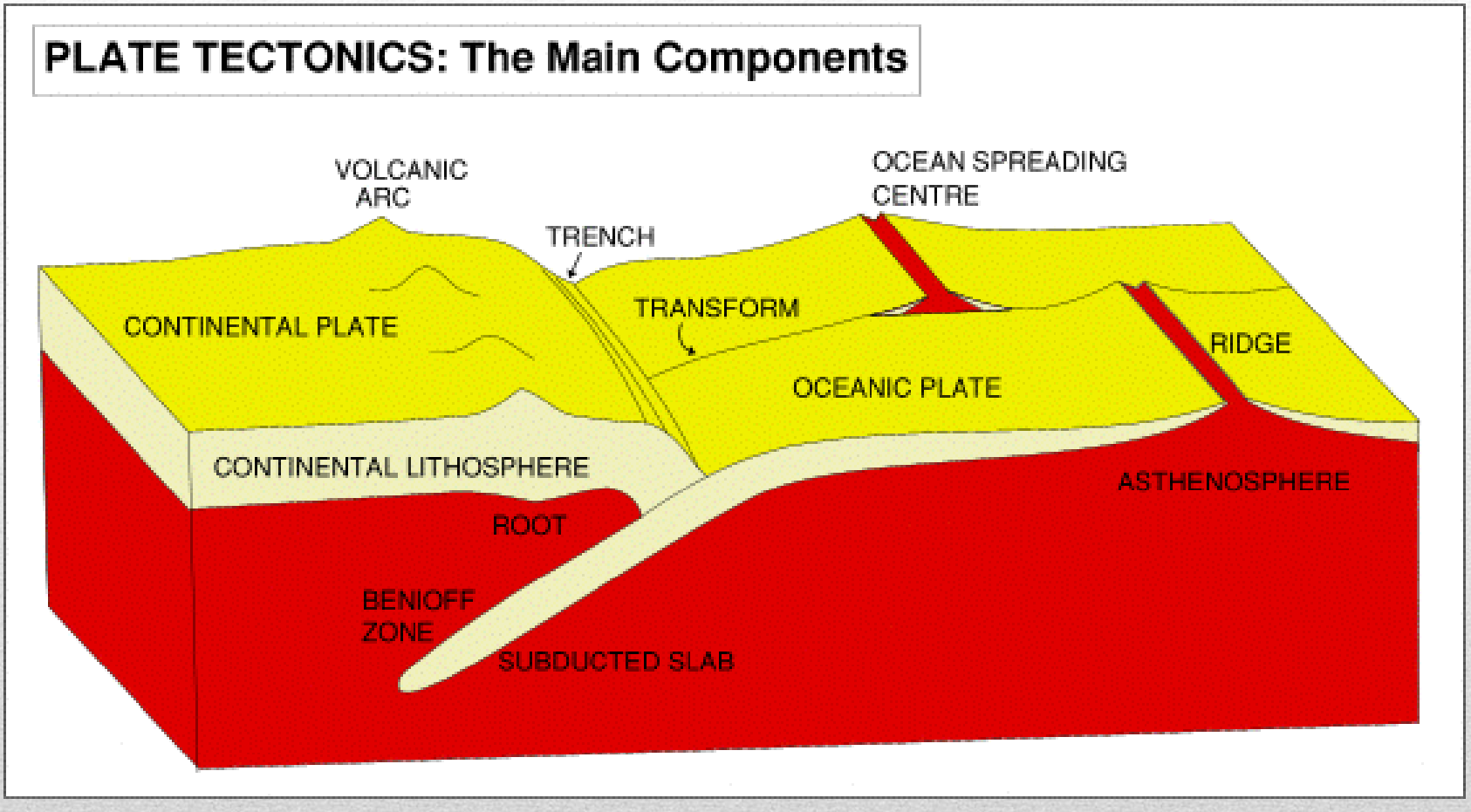
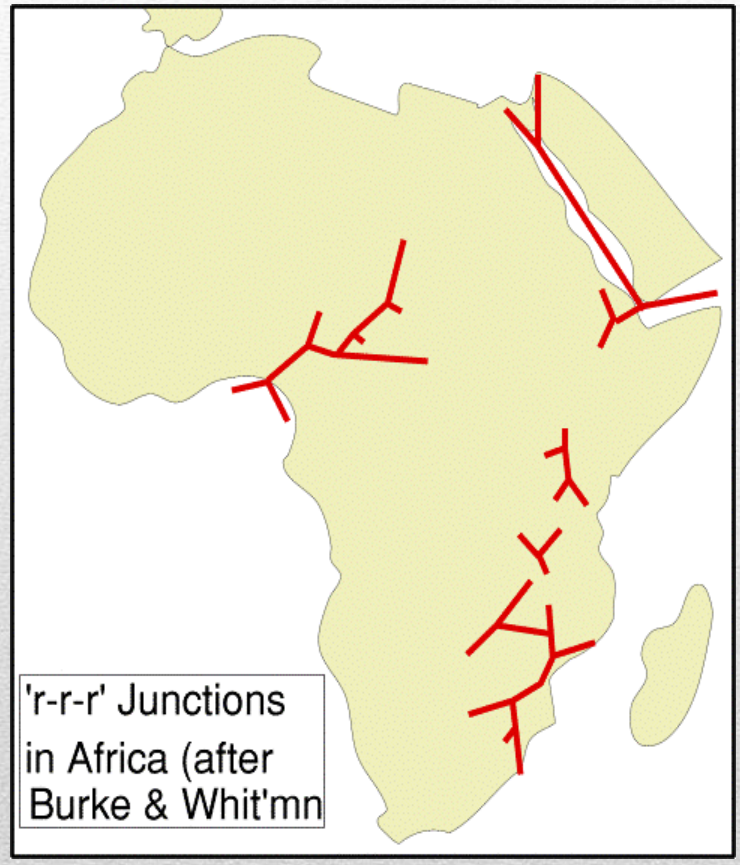
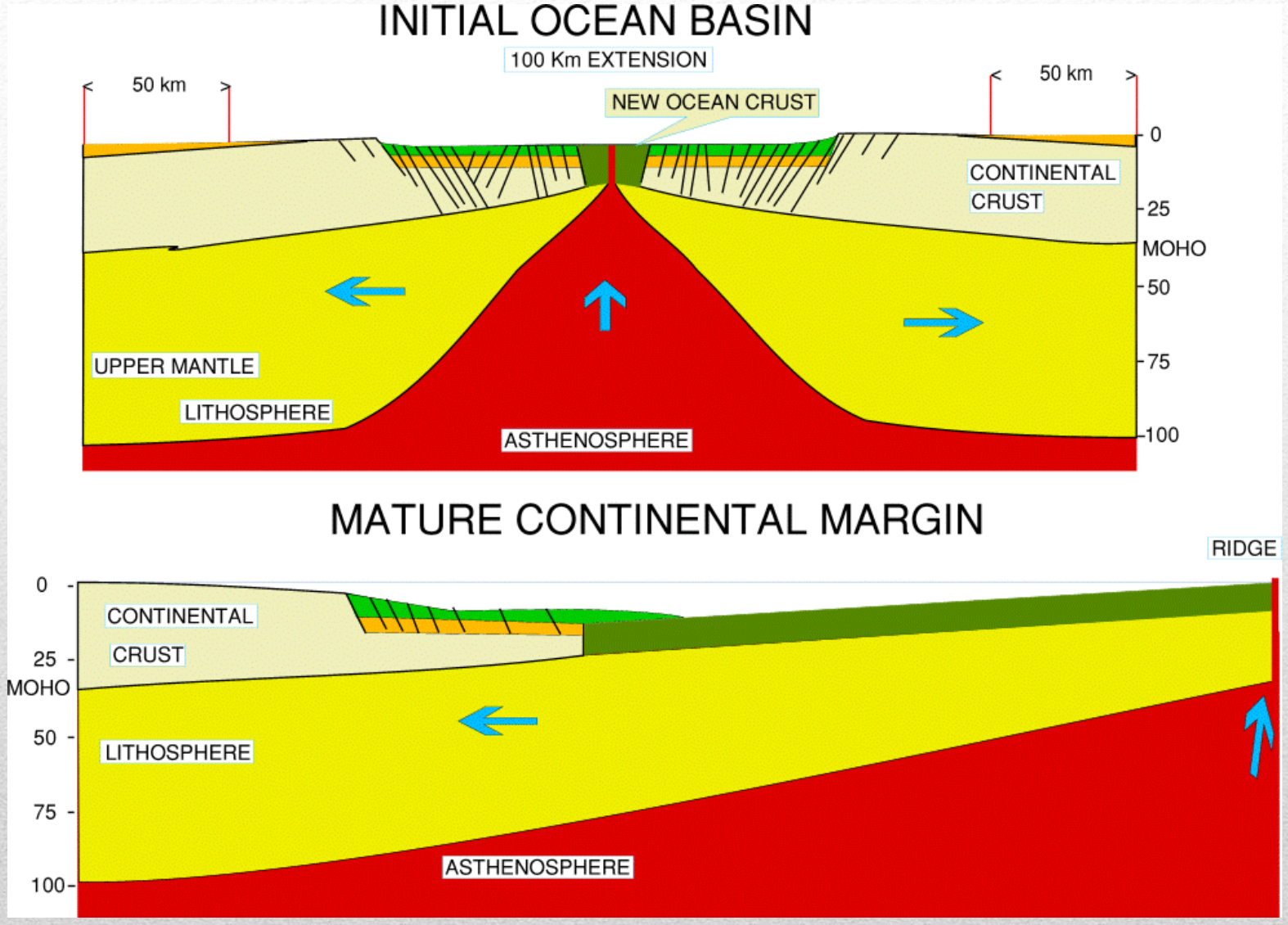


PLATE TECTONICS: The Main Components
VOLCANIC ARC
OCEAN SPREADING CENTRE
TRENCH
TRANSFORM
CONTINENTAL PLATE
RIDGE
OCEANIC PLATE
CONTINENTAL LITHOSPHERE
ASTHENOSPHERE
ROOT
BENIOFF ZONE
SUBDUCTED SLAB

Plate Boundaries

- **<u>Divergent Boundaries</u>** – where plates **<u>stretch apart</u>**
  - **Ocean divergent boundaries**
    - Where magma from the asthenosphere pushes up through the cracks in the ocean floor – **Mid ocean ridge**
  - **Continental divergent boundaries**
    - **Continental rift valleys– East African Rift Valley**





65cd_DivergBound_SP.swf

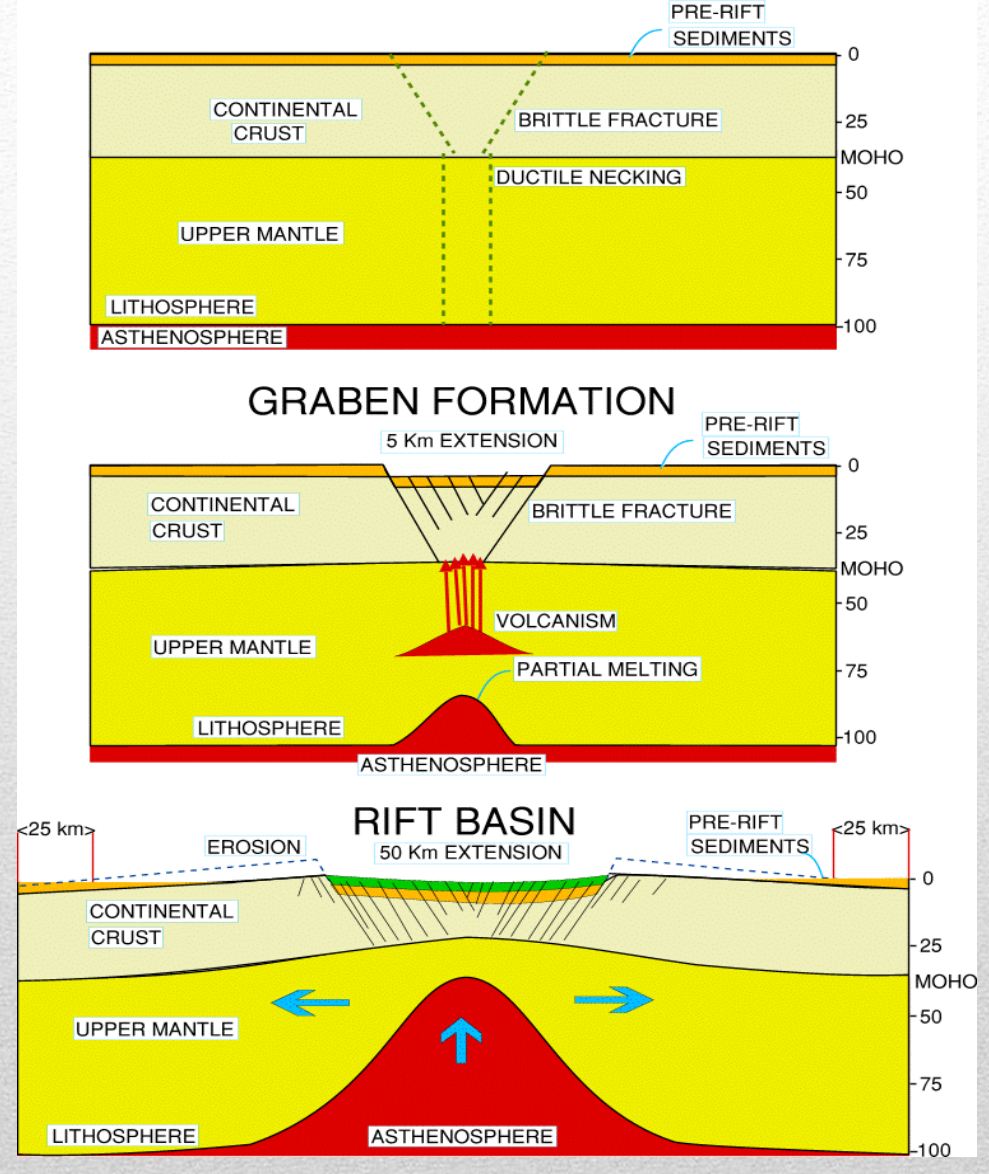
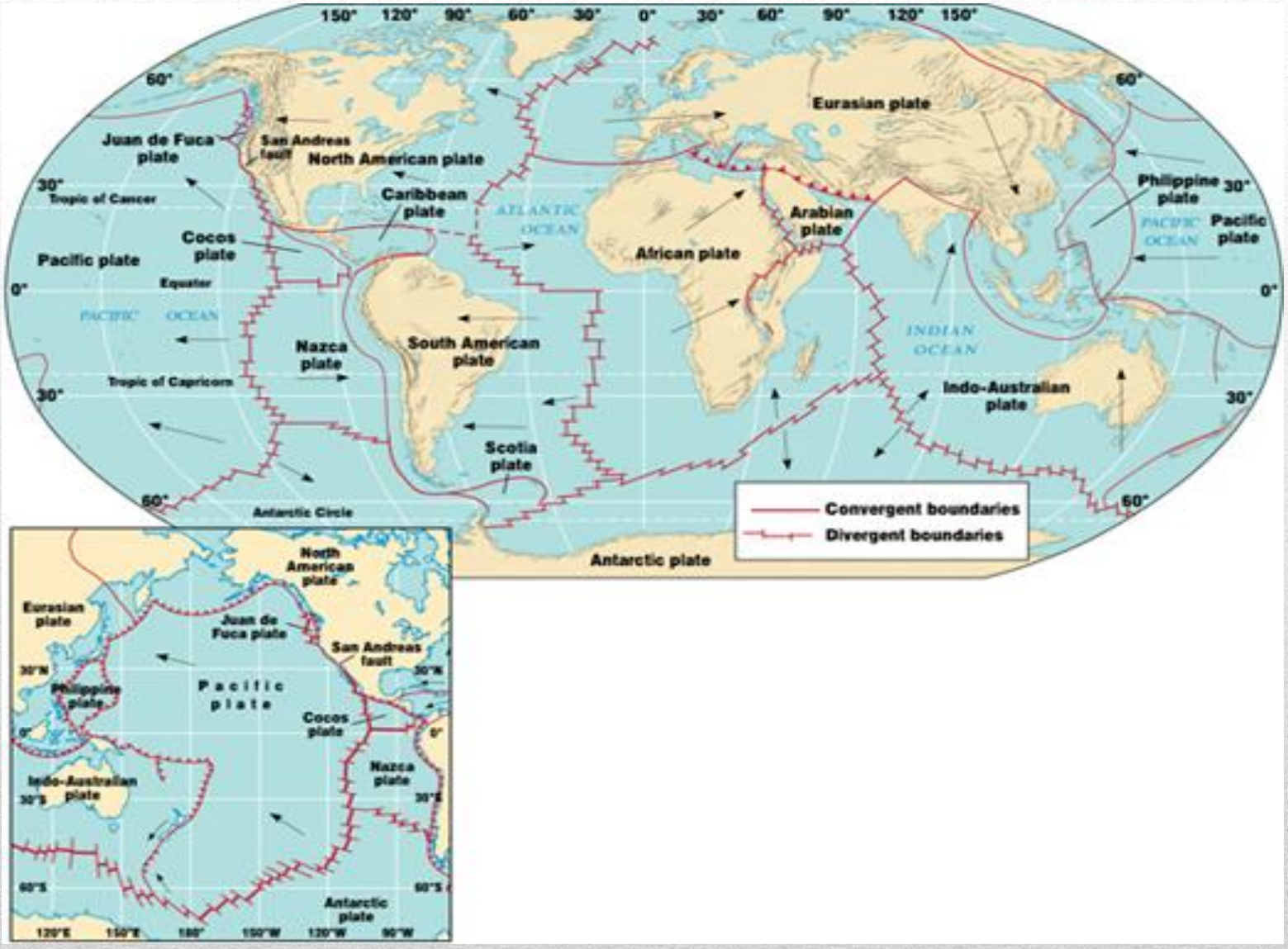

PRE-RIFT
SEDIMENTS
0
CONTINENTAL
CRUST
BRITTLE FRACTURE
25
MOHO
DUCTILE NECKING
50
UPPER MANTLE
75
LITHOSPHERE
100
ASTHENOSPHERE
GRABEN FORMATION
5 Km EXTENSION
PRE-RIFT
SEDIMENTS
0
CONTINENTAL
CRUST
BRITTLE FRACTURE
25
MOHO
VOLCANISM
50
UPPER MANTLE
PARTIAL MELTING
75
LITHOSPHERE
100
ASTHENOSPHERE
RIFT BASIN
25 km
EROSION
50 Km EXTENSION
PRE-RIFT
SEDIMENTS
25 km
0
CONTINENTAL
CRUST
25
MOHO
50
UPPER MANTLE
75
LITHOSPHERE
ASTHENOSPHERE
100

Plate Boundaries

- **<u>Convergent Boundaries</u>**– where plates **collide destructive** boundaries

  - Most **<u>massive and spectacular of earthly landforms</u>**
    - **Mountains & volcanoes**
    - **Deep ocean trenches**

30cd_SeaFloor_v3_MnH.swf

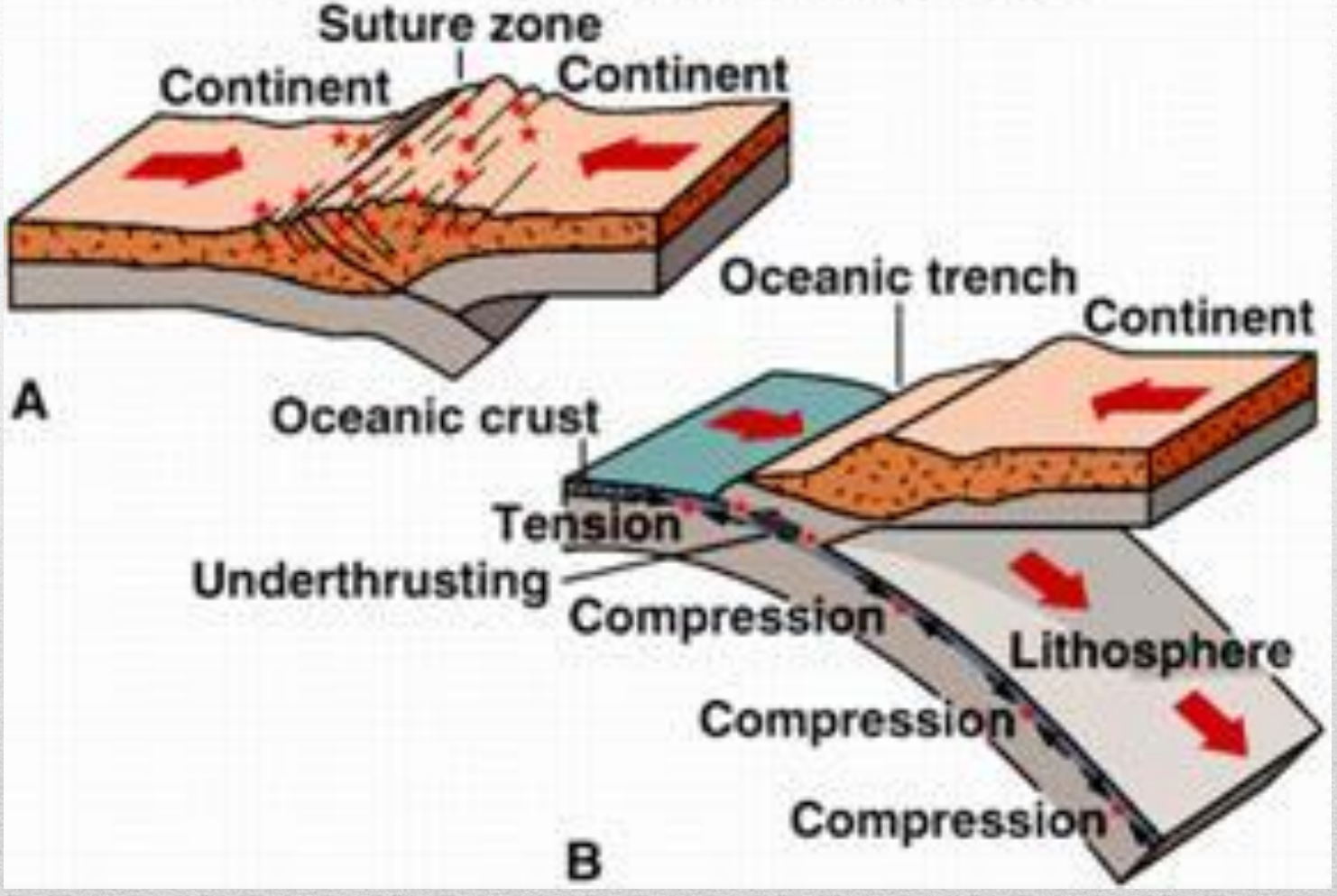

Juan de Fuca plate
San Andreas fault
North American plate
Eurasian plate
Philippine plate
Pacific plate
Caribbean plate
Arabian plate
Cocos plate
African plate
Pacific plate
Equator
Tropic of Cancer
Tropic of Capricorn
Nazca plate
South American plate
Indo-Australian plate
Scotia plate
Antarctic Circle
Antarctic plate
Convergent boundaries
Divergent boundaries
ATLANTIC OCEAN
PACIFIC OCEAN
INDIAN OCEAN
Eurasian plate
North American plate
Juan de Fuca plate
San Andreas fault
Philippine plate
Pacific plate
Cocos plate
Nazca plate
Indo-Australian plate
Antarctic plate

Ocean-continental convergence

- **Continental crust- always <u>overrides</u>**

  Ocean crust creating **<u>ocean trench</u>**
- **<u>Earthquakes- volcanoes associated</u>**
  - Once thought the **<u>plate melted– new evidence</u>**
  - **Water from ocean crust lowers the melting point causing it to melt- magma rises to develop volcanoes**

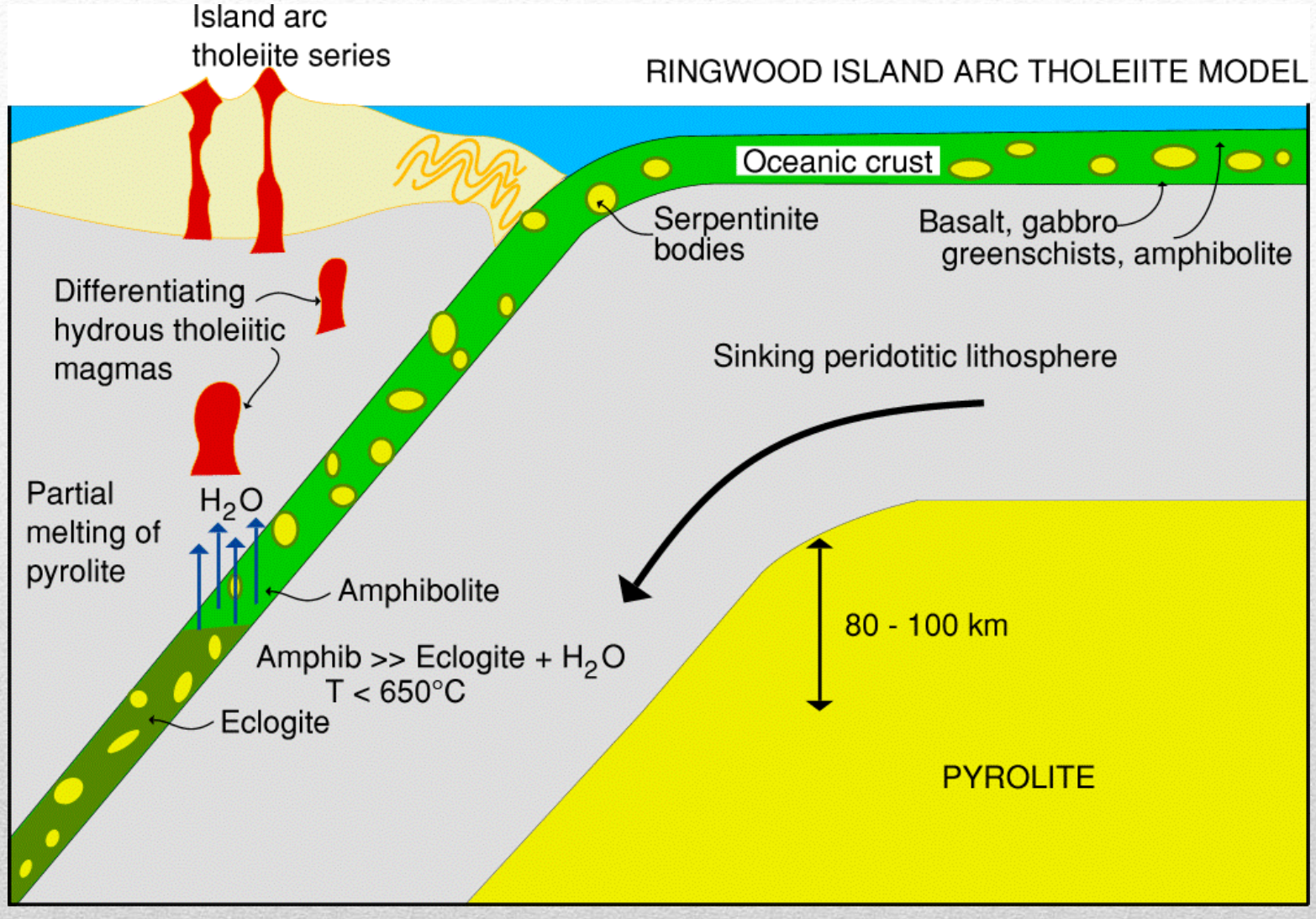
Convergent Boundaries



Ocean-Ocean Convergence

- **Convergence between two ocean plates**
- **Creates a volcanic island arc**
  - **Aleutian or Mariana Islands, or mature islands like Japan**

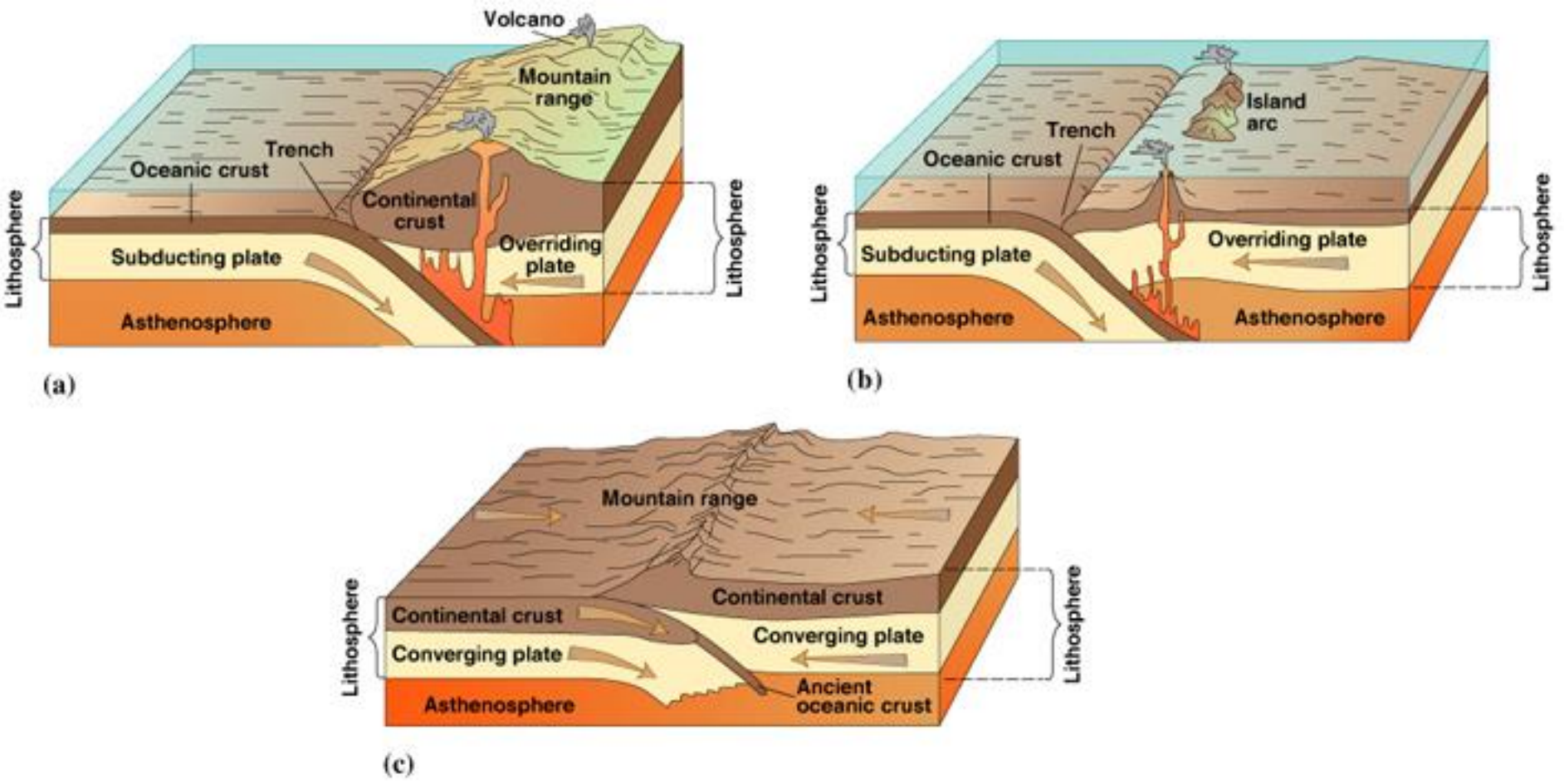
35cd_VolcanicAct_v3_MnH.swf


Island arc
tholeiite series
RINGWOOD ISLAND ARC THOLEIITE MODEL
Oceanic crust
Serpentinite
bodies
Basalt, gabbro
greenschists, amphibolite
Differentiating
hydrous tholeiitic
magmas
Sinking peridotitic lithosphere
Partial
melting of
pyrolite
H_2O
Amphibolite
Amphib >> Eclogite + H_2O
T < 650°C
Eclogite
80 - 100 km
PYROLITE

Continental-Continental Convergence

- **No subduction—crust is too buoyant**
  - **Huge mountain ranges**
    - Alps, Rocky Mountains, Himalayas
  - **Volcanoes are rare- but shallow**
  - **Focus earthquakes and regional metamorphism are common**
- **Transform Boundaries**
  - **Two plates slip past each other**
  - **Strike-slip fault**
    - **Conservative boundary-associated with great number of seismic activity**
      - California great example


Koyukuk terrane
ALASKA
Aleutian Trench
Wrangellia terrane
PACIFIC PLATE
CANADA
Alexander terrane
JUAN DE FUCA PLATE
Cascadia Trench
NORTH AMERICAN PLATE
Sonoma terrane
SAN ANDREAS FAULT
UNITED STATES
Salton Trough
Guerrero terrane
MEXICO
East Pacific Rise
EXPLANATION
Island arc
Submarine deposits
Ancient ocean floor
Attached fragments
Ancient continental interior (craton)
Divergent boundary
Convergent boundary
Transform boundary

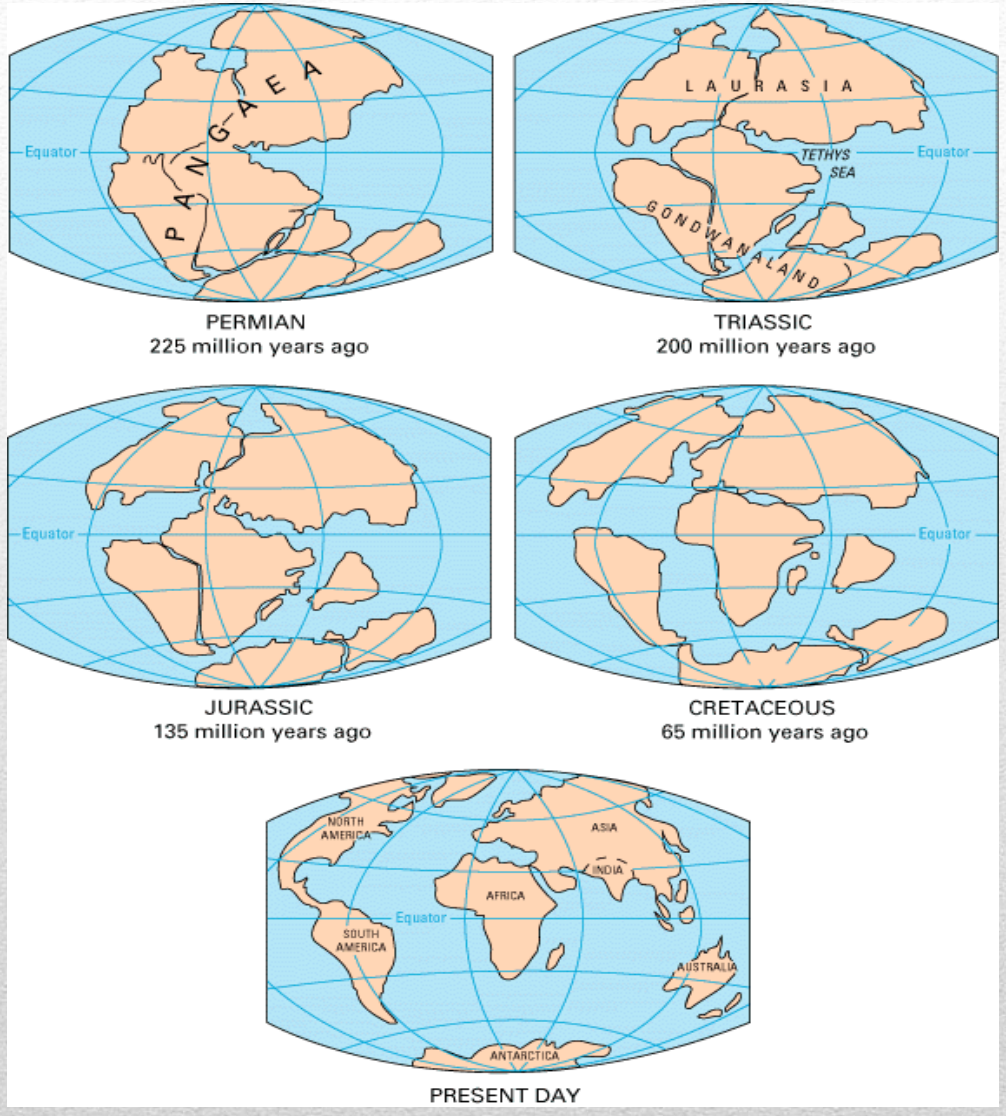


56cd_PlateBound_SP.swf

Assembly & Breakup of Pangaea

- **Summary of the time line**
  - **450 million years** – **5 continents**- merged together to form **Pangaea**
  - **Next 200 million years; one continent**
  - **200 million years** – **Pangaea starts to break up**– **Laurasia/Gondwanaland**- then to even smaller pieces
  - **135 million years --** North and South Atlantic Oceans begin to open, separating South America and Africa, Mediterranean Sea began to close as Africa began to rotate northward toward Asia
  - **65 million years --**North and South Atlantic Oceans joined; South America was new Continent and moving westward, Andes growing, as South America overrides the Pacific Plate. Rockies were rising but not the Sierras

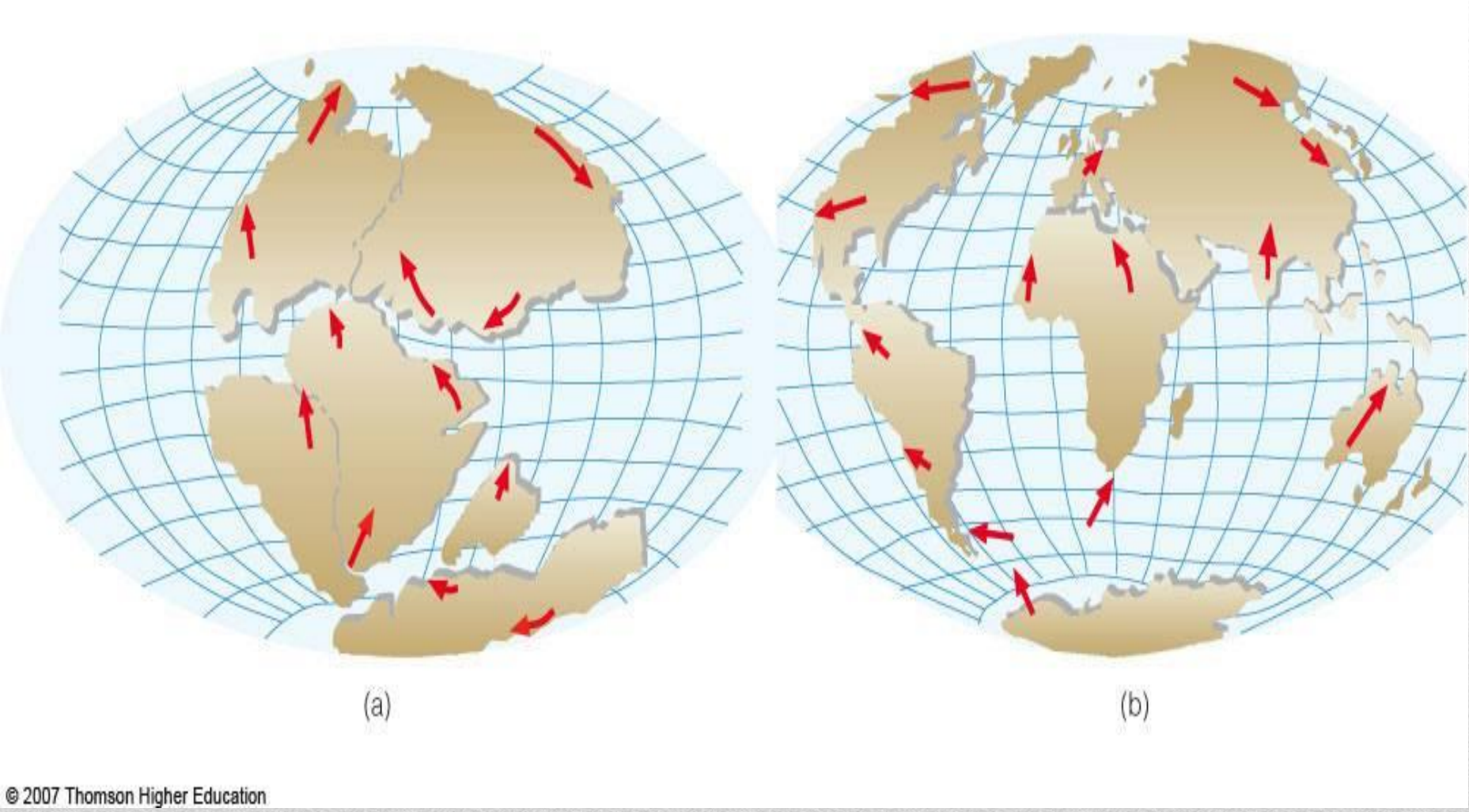
Pangaea begins to break apart into present continents


PANGAEA
Equator
PERMIAN
225 million years ago
LAURASIA
TETHYS SEA
Equator
GONDWANALAND
TRIASSIC
200 million years ago
Equator
JURASSIC
135 million years ago
Equator
CRETACEOUS
65 million years ago
NORTH AMERICA
ASIA
INDIA
AFRICA
Equator
SOUTH AMERICA
AUSTRALIA
ANTARCTICA
PRESENT DAY

Assembly & Breakup of Pangaea

- **“Today”** South America connected to North America
- North America separated from Europe
- Europe, Australia has split from Antarctica
- India collided with Eurasia-thrusting up the Himalayas
- All continents are still in motion except for Antarctica
- Africa is splitting along Great Rift Valley rotating counterclockwise

66cd_PlateMoTime_SP.swf

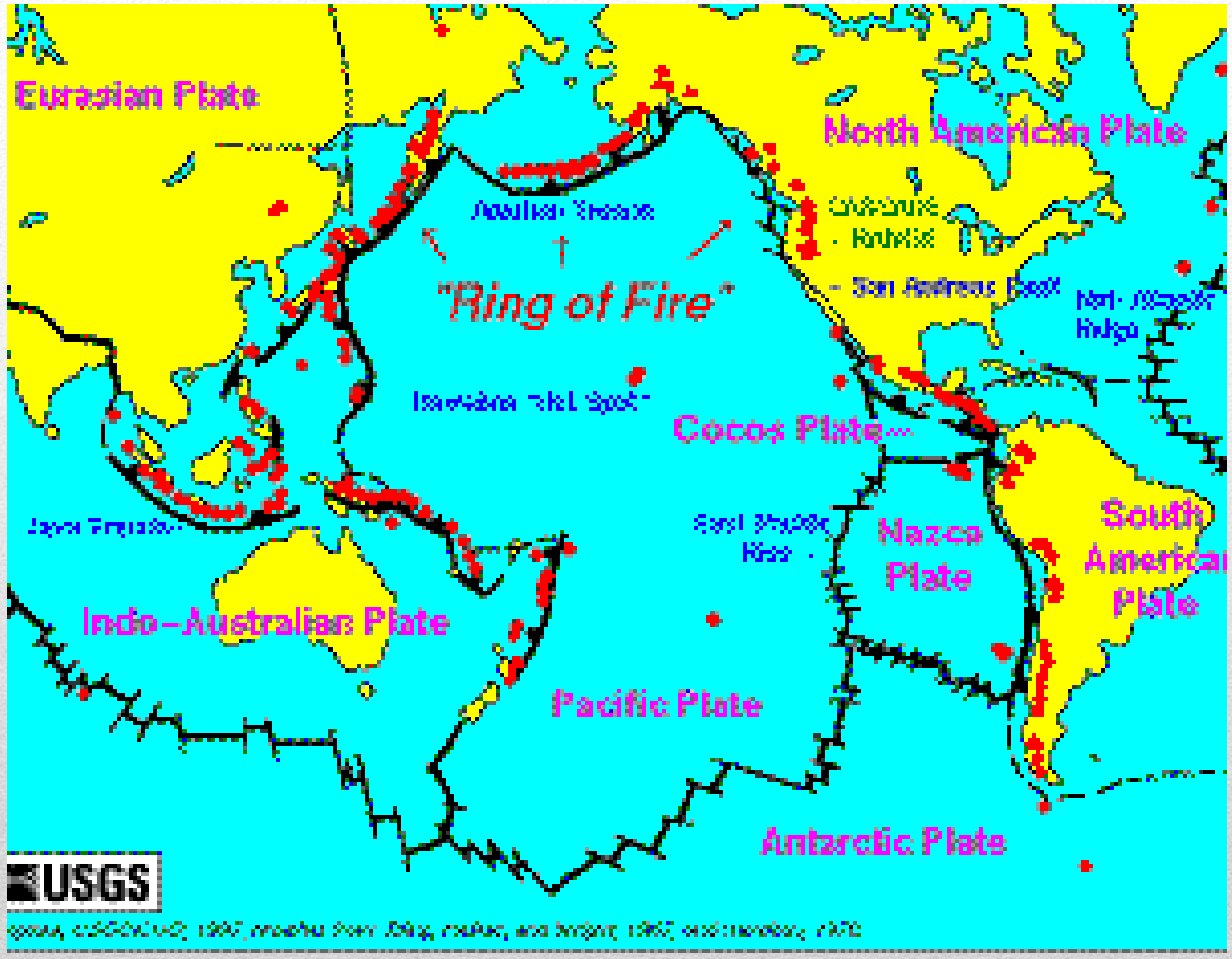


Future of the continents

- **50 million years from now**
  - Australia will straddle the equator is huge tropical island
  - Africa may pinch the Mediterranean shut
  - East Africa becomes large island like Madagascar
  - The Atlantic will widen while the Pacific will shrink
  - Southern California, now a chilly island will pass San Francisco heading for its ultimate destination in the Aleutian Trench of the Gulf of Alaska

Pacific Ring of Fire

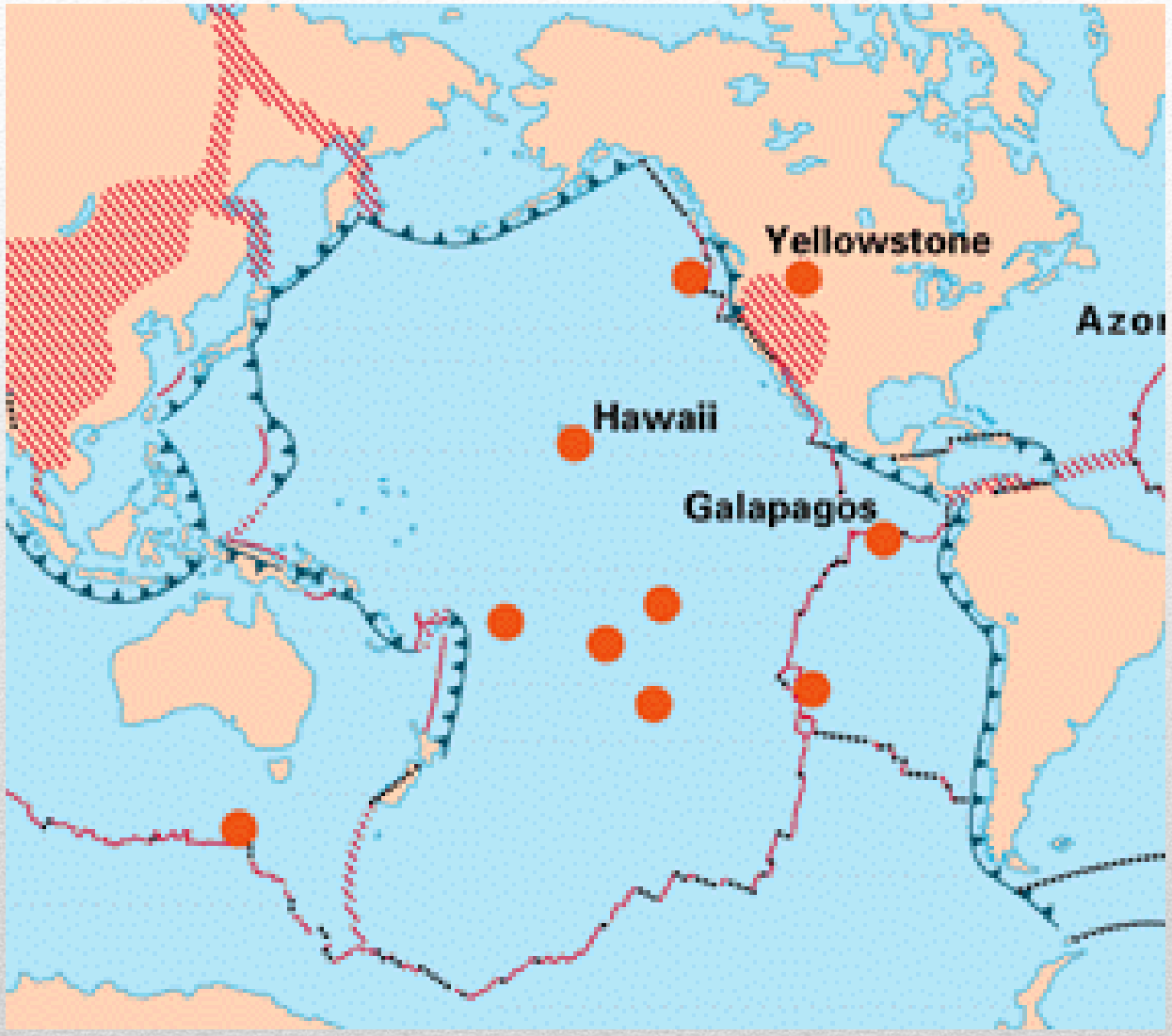
- **Ring of active volcanoes surrounding the Pacific Ocean**
- **Found primarily along the subduction zones of the Pacific Basin plate boundaries**
- **Some segments along the transform and divergent plate boundaries**


Eurasian Plate
North American Plate
"Ring of Fire"
Cocos Plate
Nazca Plate
South American Plate
Indo-Australian Plate
Pacific Plate
Antarctic Plate
USGS

Additions to the Basic Plate Tectonic Theory

- **Mantle Plumes**
  - Spots of volcanic activity caused by a thin Earth's crust allowing the magma to move to the surface
  - These are called **Mantle Plumes or Hot Spots**
  - **Hawaii and Yellowstone are known Hot Spots**
  - As the plate moves across the Hot Spot, a **hot spot trail is left, such as the Hawaiian Islands**
  - **Mantle plumes help to explain volcanic activity in the middle of plates and help to distinguish the direction of the plate's movement.**

45cd_HotSpot_SP.swf

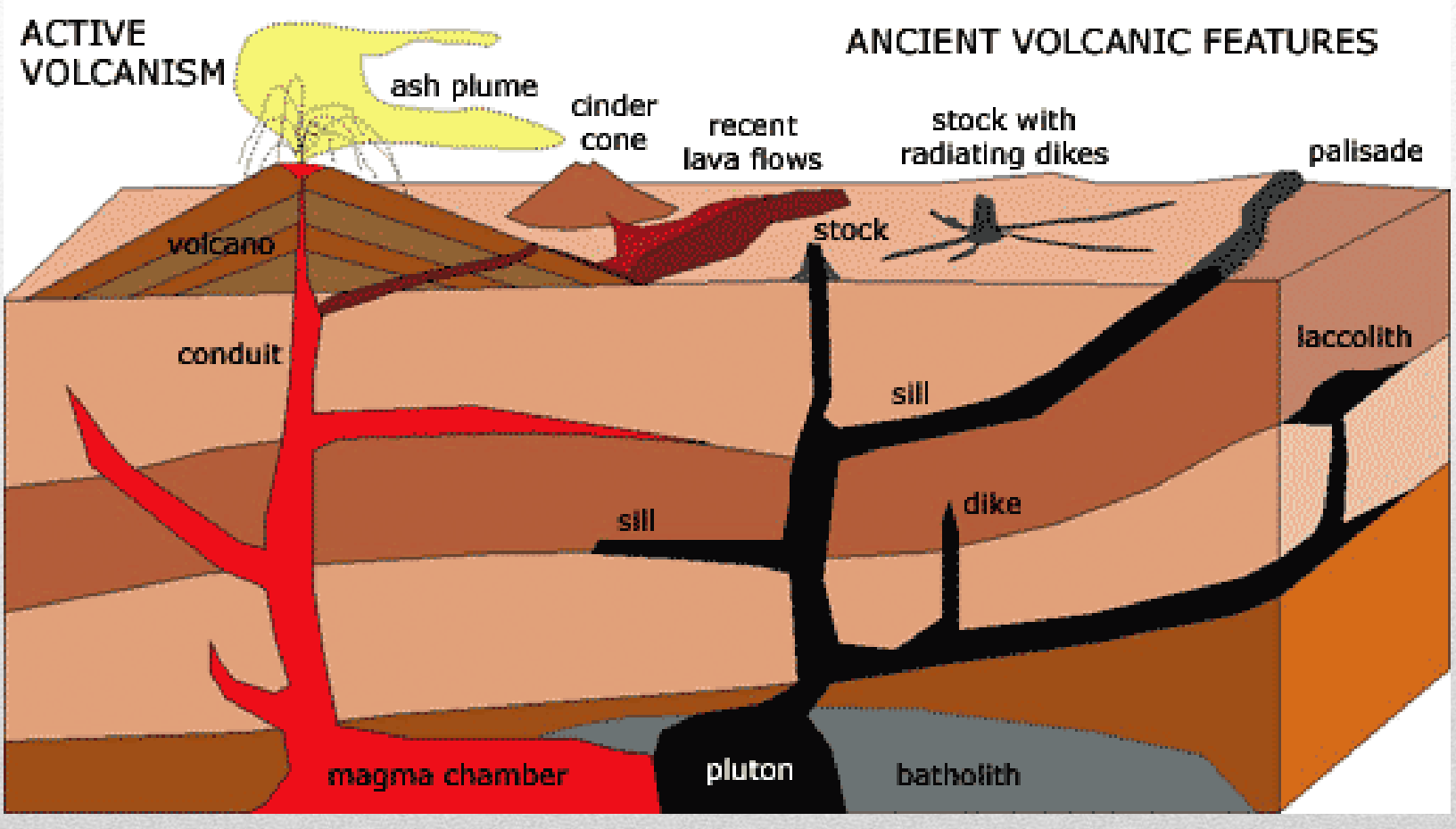

Yellowstone
Hawaii
Galapagos

Additions to the Basic Plate Tectonic Theory

- **Accreted Terranes**
  - A **terrane** is a **small-to-medium mass of lithosphere** that may have been carried a long distance by a drifting plate that eventually converges with another plate
  - **A terrane** that is **too buoyant** to be **subducted** in the collision, **but is fused and fragmented** in the **process is said to be accreted**.
  - **Terranes are distinctive geologically, the rock is different from the Plate they are accreted to**.

Vulcanism

- **General term that refers to all phenomena connected with the origin and movement of molten rock**
  - **Two categories–Plutonic Activities** (below the surface of the crust)
    - **Volcanism – extrusive**
    - **Intrusive volcanism (shallow)**
      - **Plutonic (intrusive, very deep)**


ACTIVE VOLCANISM
ash plume
cinder cone
recent lava flows
ANCIENT VOLCANIC FEATURES
stock with radiating dikes
palisade
volcano
stock
conduit
laccolith
sill
dike
sill
magma chamber
pluton
batholith

Volcanism

- **<u>Magma</u>**
  - **Molten mineral material below the surface** –
  - **Lava when extruded to the surface**.
  - **Explosive material is pyroclastic material**
  - **Distribution**—Most found in the Ring of Fire or at subduction zones
- **Magma Chemistry and style of eruptions**
  - **Felsic Magma** – Rhyolite and Granite
    - Explosive eruptions

    Mafic Magma – Basalt and Gabbro
    - Slow moving, non-explosive

Volcanoes

- Volcanic Activity
  - Revitalizes the crust
- Lava Flows
  - Spreads outward at the altitude of the surface over which it flows
  - Solidifies in a horizontal orientation, with stratification
    - Large flows from mid ocean flows are called flood basalt

Kinds of Volcanoes

- **Shield**
  - Broad, gentle slope,
  - Layers of lava flows
  - Basaltic magma, quiet eruptions
- **Composite**
  - Large, steep, symmetrical
  - Layers of lava, proclastic
  - Magma andesitic, both explosive and quiet eruptions

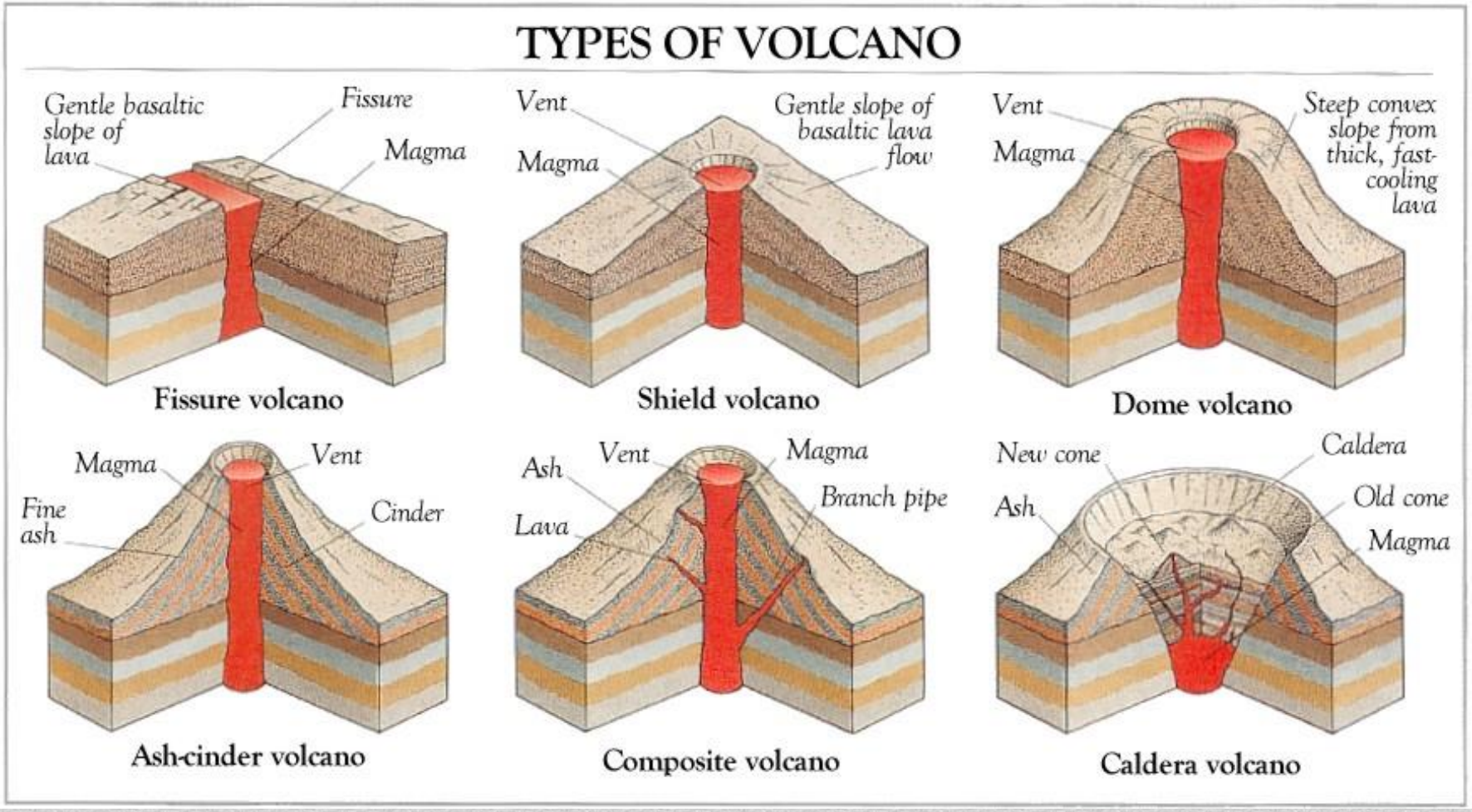
61cd_VolTypes_SP.swf

Kinds of Volcanoes

- **Lave Dome**
  - Small, less than 2000 ft. high, irregular shape
  - Solidified thick viscous lava
  - Magma high in silica, often rhyolite
- **Cinder Cone**
  - Small Steep-sided.
  - Loose proclastic material
  - Magma varies from basaltic to proclastic

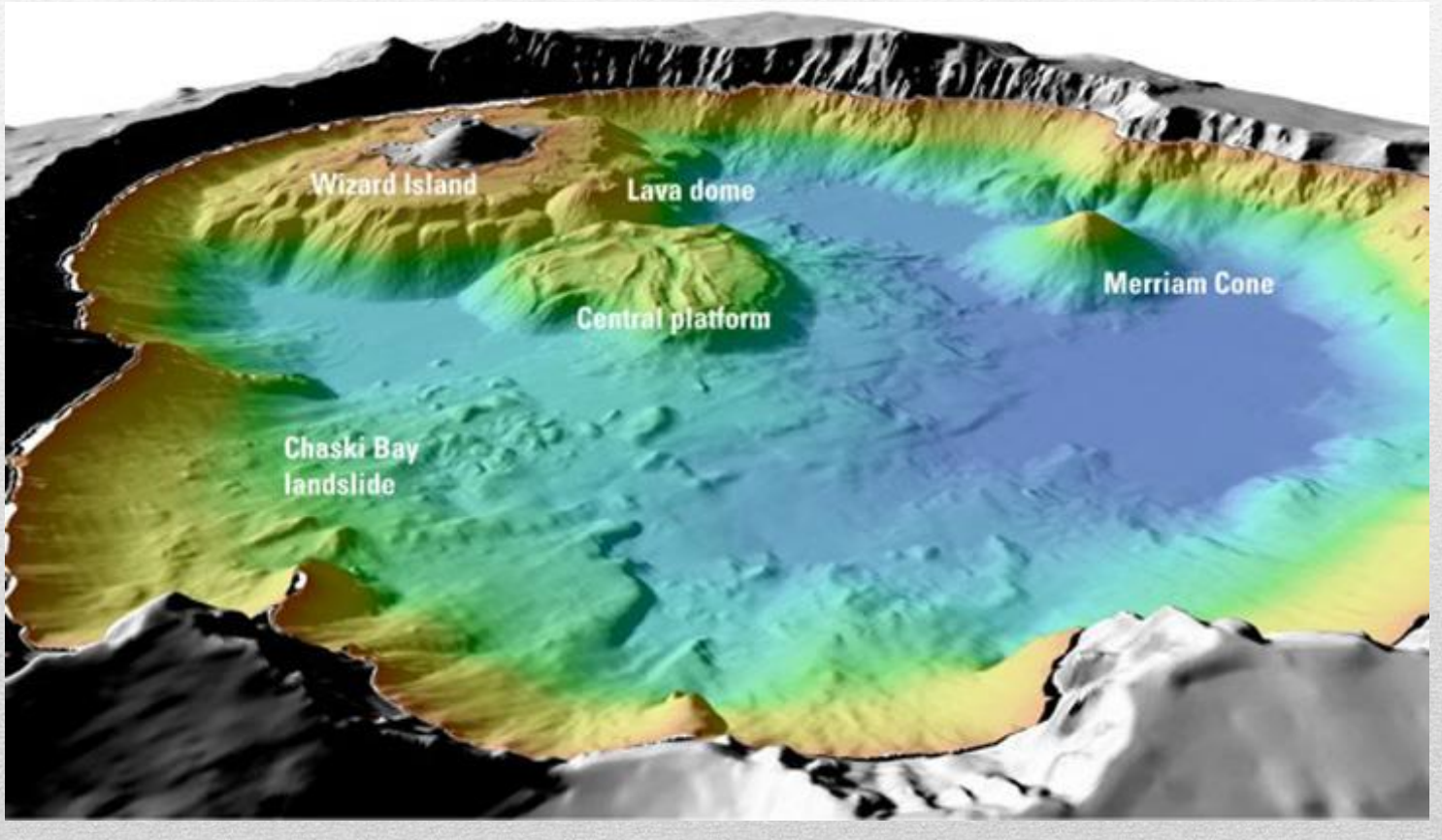
- **<u>Calderas—a crater produced from a collapsed volcano</u>**

Volcanoes


TYPES OF VOLCANO
Gentle basaltic slope of lava
Fissure
Magma
Fissure volcano
Vent
Magma
Gentle slope of basaltic lava flow
Shield volcano
Vent
Magma
Steep convex slope from thick, fast-cooling lava
Dome volcano
Magma
Vent
Fine ash
Cinder
Ash-cinder volcano
Ash
Vent
Magma
Lava
Branch pipe
Composite volcano
New cone
Caldera
Ash
Old cone
Magma
Caldera volcano

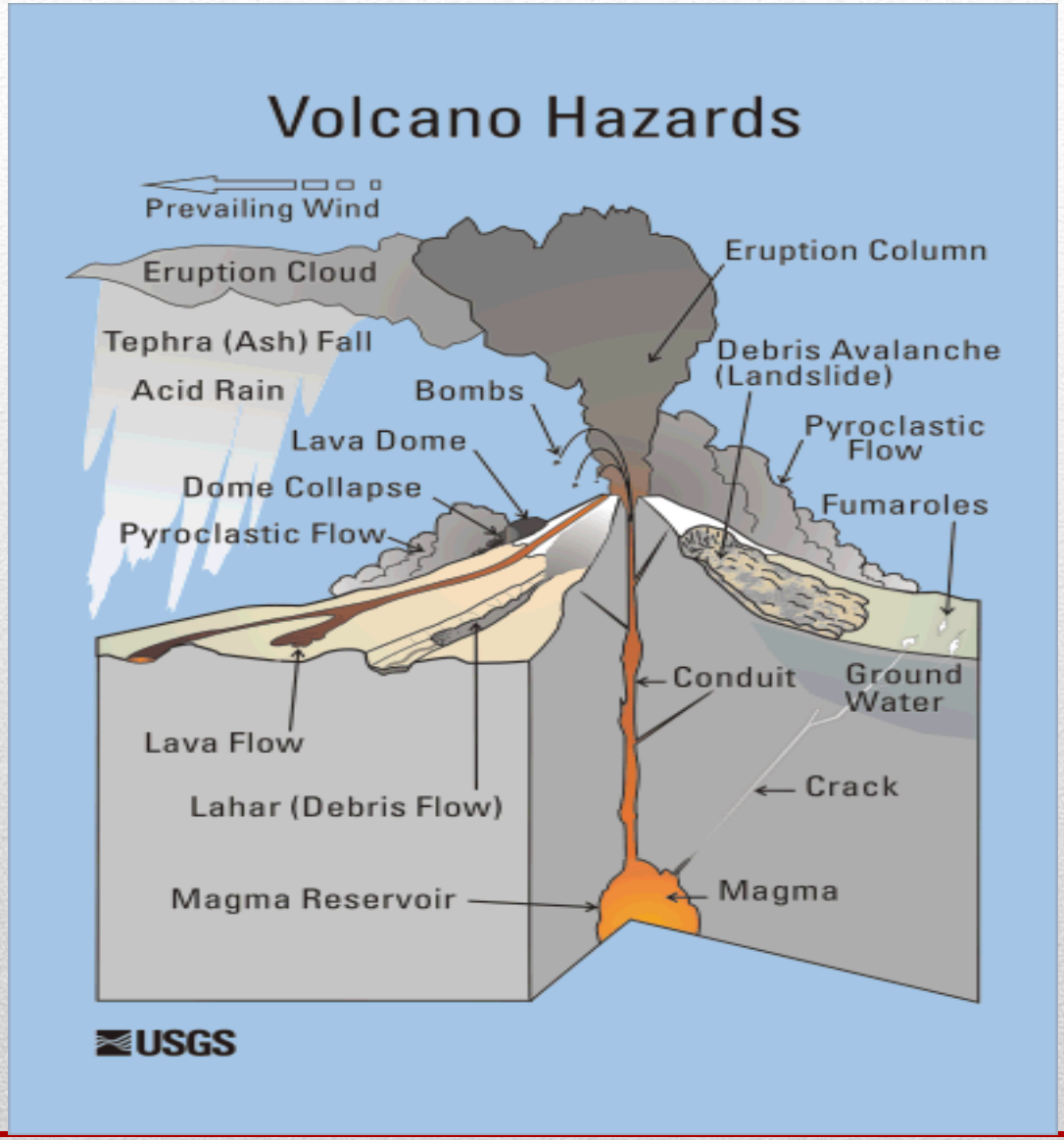
Volcanoes

Crater Lake -- Caldera



Volcanic Hazards

- **Volcanic Gases**
  - Emissions of noxious gases such as carbon dioxide, sulfur dioxide, hydrogen sulfide, and fluorine
- **Lava flows**
  - Rarely cause loss of life, but cause lots of damage
- **Eruption Column and Clouds**
  - Changes the air quality and weather
- **Proclastic flows**
  - Collapse of the lava dome or explosive eruption causes high speed avalanche of searing hot gases, ash, and rock fragments
- **Volcanic Mudflows (Lahars)**
  - A loose mantle of ash and proclastic flow on the sides of a volcano slides during a heavy rain storm.



69cd_MtStHelens_SP.swf

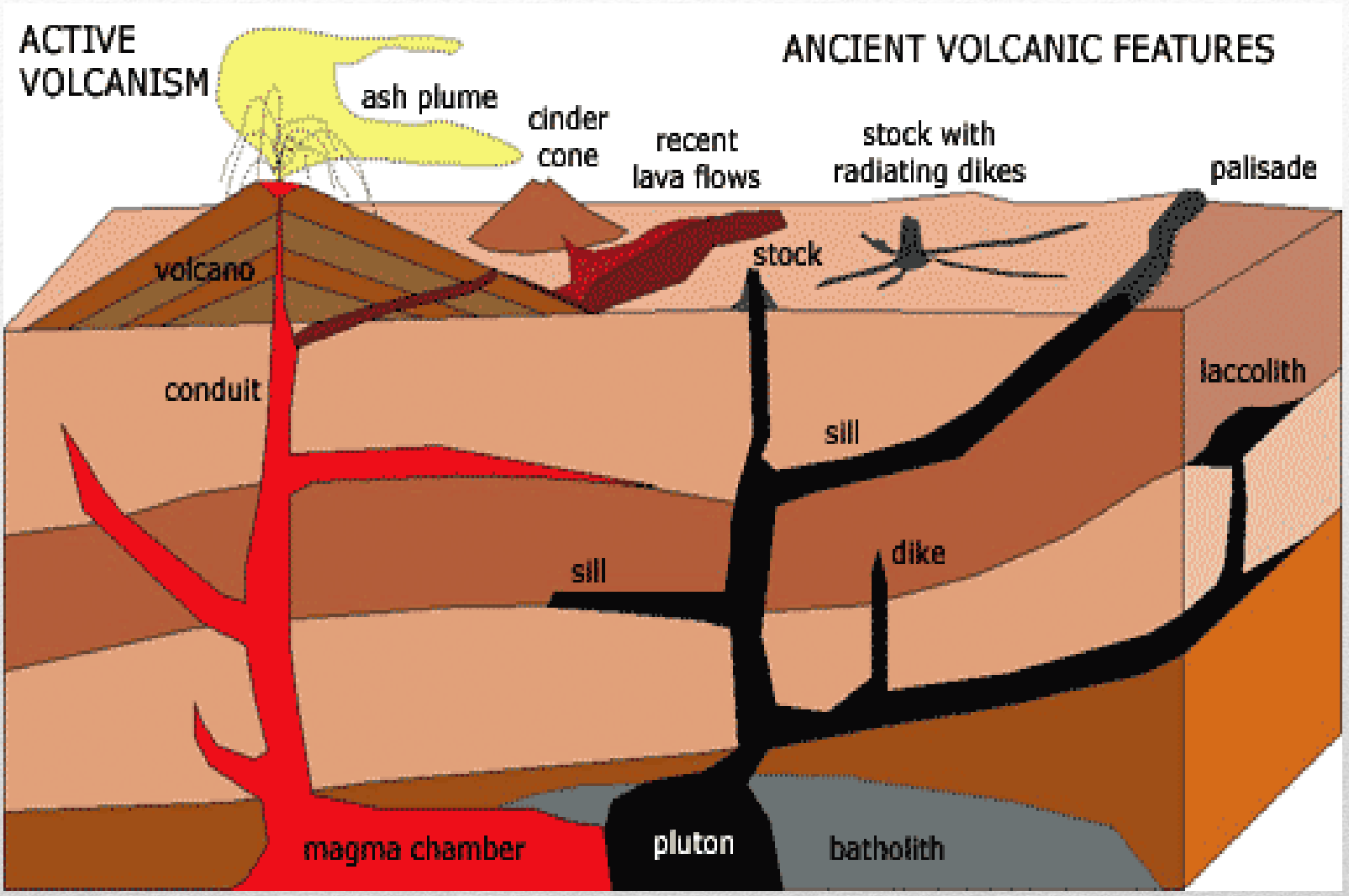
Igneous Features

- **Igneous intrusions – when the magma solidifies below the surface producing a igneous intrusion**
- **Types of intrusions**
  - **<u>Batholiths</u> -- a subterranean igneous body of indefinite depth and enormous in size. Often the core of mountain ranges.**
  - **<u>Stocks</u> – Similar to the batholiths but much smaller. Often an offshoot of batholiths.**
  - **<u>Laccoliths</u>– produces by slow-flowing viscous magma is forced between horizontal laye4rs of preexisting rock.**

24cd_IgneousFeat.swf

Igneous Features

- **Igneous intrusions – when the magma solidifies below the surface producing a igneous intrusion**
  - **<u>Dikes</u> – a vertical or nearly vertical sheet of magma thrust upward into preexisting rock**
  - **Sills– a long, thin intrusive body with its orientation determined by the structure of the preexisting rocks.**
  - **<u>Veins</u> – least prominent- thin veins of igneous rock that are pushed up through small fractures of preexisting rocks.**


ACTIVE VOLCANISM
ash plume
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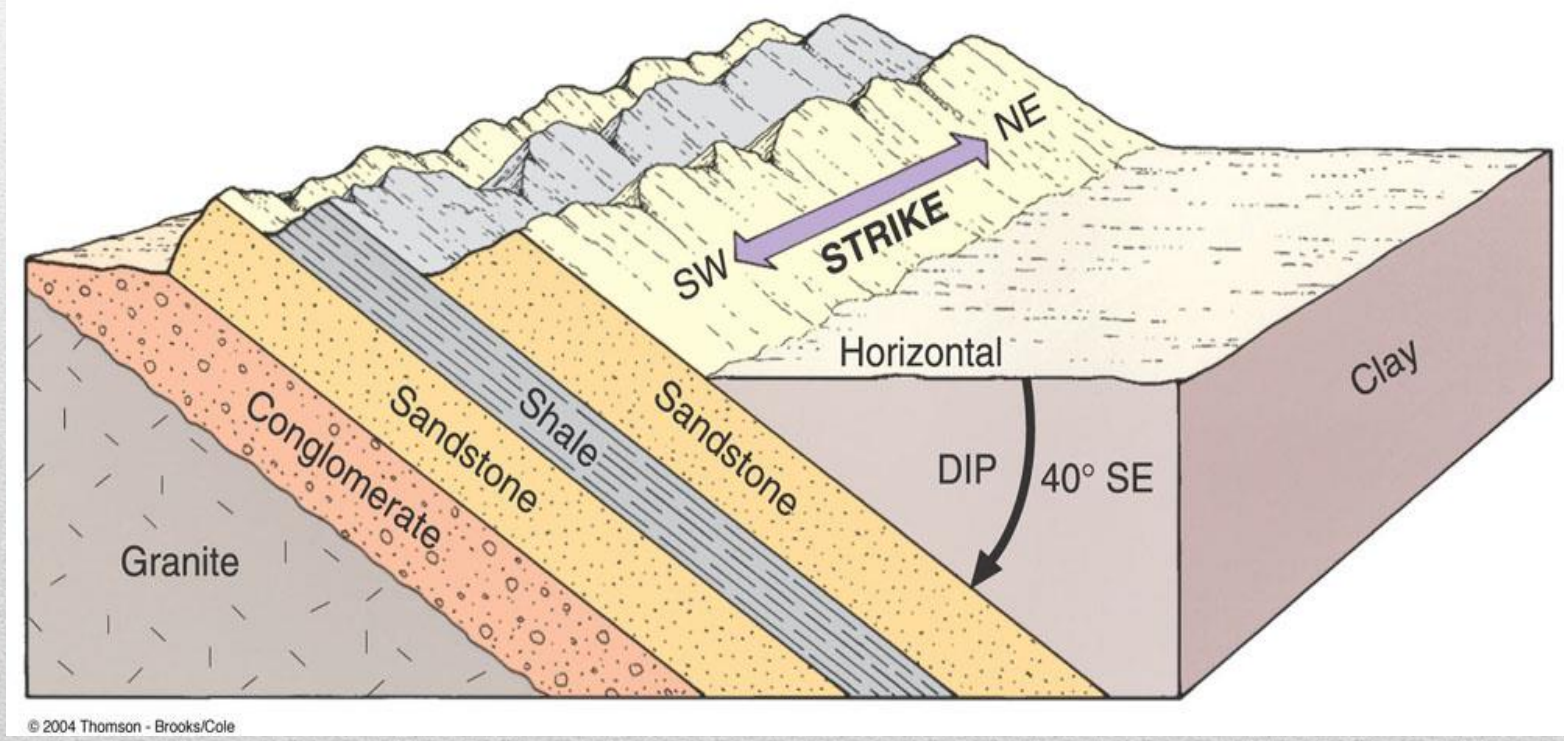
recent lava flows
ANCIENT VOLCANIC FEATURES
stock with radiating dikes
palisade
volcano
stock
conduit
laccolith
sill
dike
sill
magma chamber
pluton
batholith

Diastrophism

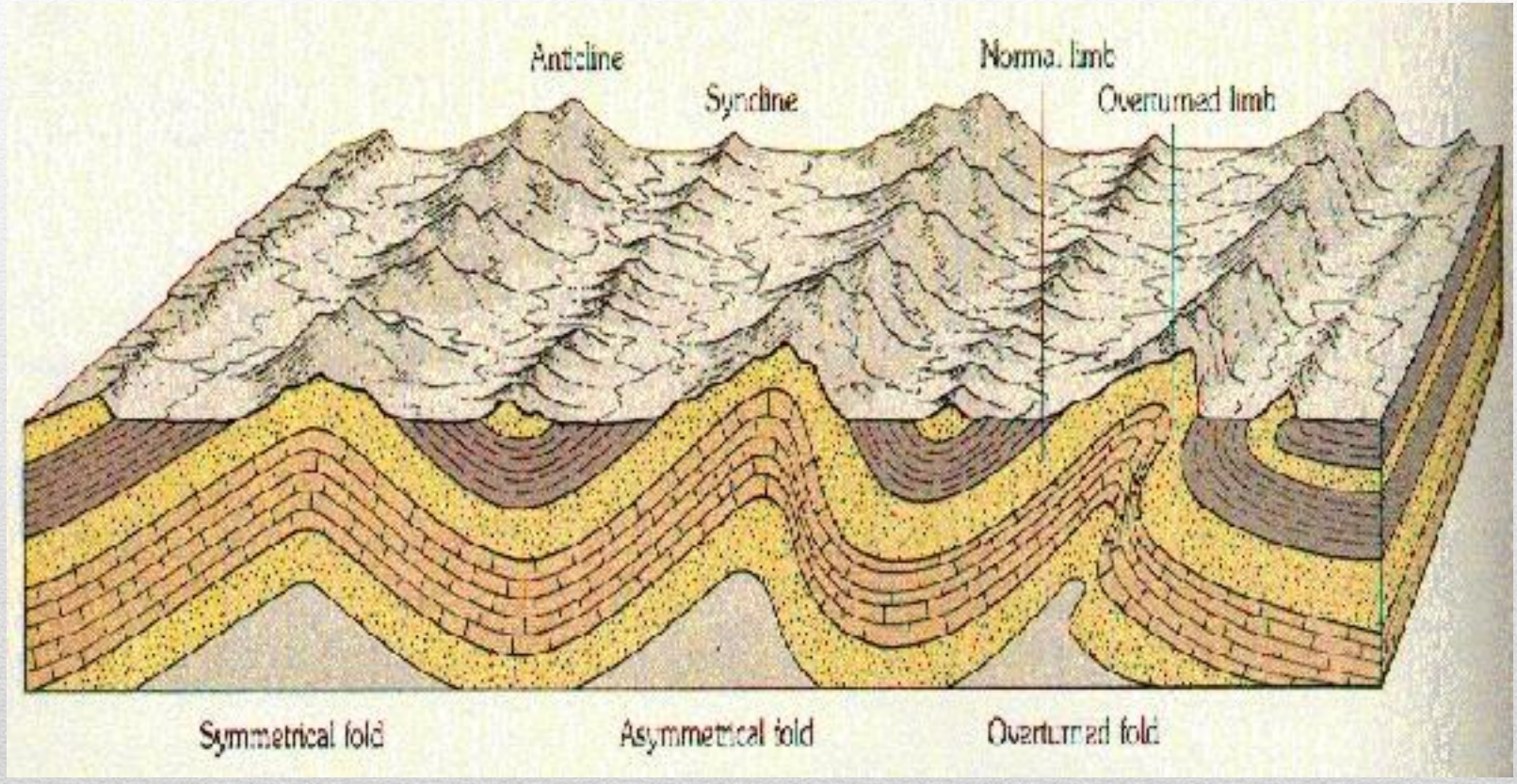
- **<u>Diastrophism</u>**—general term for the deformation of Earth's crust



Folding

- **Types**
  - **Monocline** – a one-sided slope connecting two horizontal or gently inclined strata.
  - **Anticline**– simple symmetrical upfold
  - **Syncline** – simple downfold
  - **Overturned fold** – an upfold that has been pushed so vigorously from one side that becomes over-steepened enough to have a reversal orientation
  - **Overthrust fold** – if the pressure is enough to break the over-steepened climb, older rock rides above younger rock

Folding


Anticline
Syncline
Normal limb
Overturned limb
Symmetrical fold
Asymmetrical fold
Overturned fold

Faulting

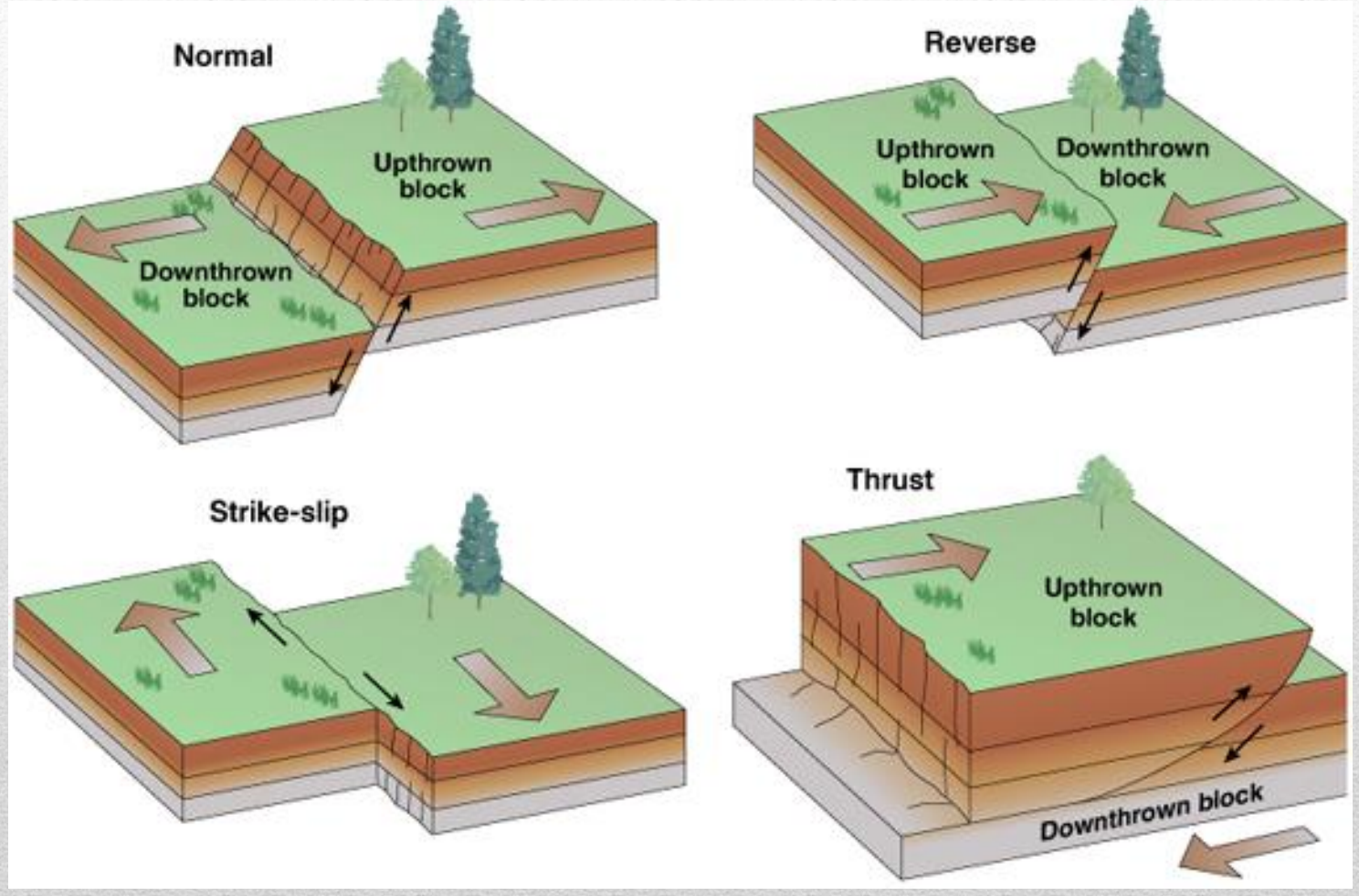
- **Faulting results when rock is broken under stress and displacement happens**
  - **Fault zones**—a area of weakness in the crust
  - **Fault line** – the intersection a fault zone with the Earth's surface
  - **Fault scarps**– steep cliffs that represent the edge of a vertically displaced block

Types of Faults

- **Normal** –results from tension stresses (pulling apart) in the crust
- **Reverse** – produced from compression, with the upthrown block rising steeply above the downthrown block
- **Thrust** – complicated in structure, compression forces the upthrown block to override the downthrown block at a relatively low angles.
- **Strike-slip** – the movement is horizontal with the adjacent blocks being displaced laterally relative to each other.

08cd_Faults.swf

Types of Faults



Landforms Associated with Faults

- **Normal Faulting**
  - **Tilted fault-block mountains** – surface block may be severely faulted and upthrown on one side without any faulting on uplift on the other.
  - **Tilted fault-block mountain range** – gentle slope and a steep slope along the fault scarp. – **Sierra Nevada Mountains**
  - **Horst and Graben** – Uplift of a block of land between two parallel faults or the land between the two faults can be thrown-down
    - Example – **Death Valley or all the of the Great Basin**
  - **Rift Valleys** – Downfaulted grabens occasionally extended for long distances as linear valleys enclosed by steep fault scarps
    - **Example – Great Rift Valley in East Africa**

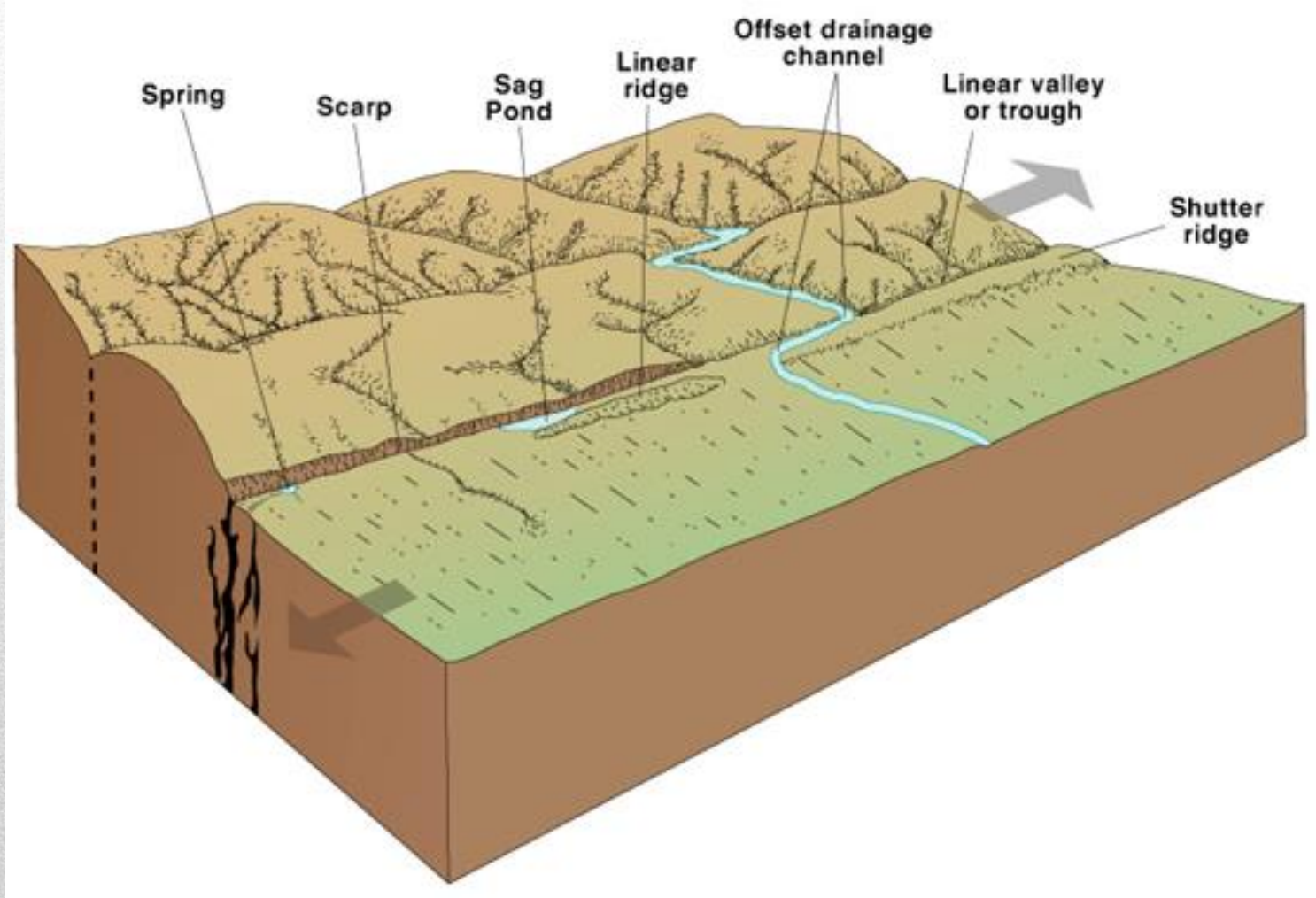
16cd_FoldsAnS_SP.swf

Landforms Associated with Faults

- **Strike-Slip Faulting**

  - **Linear Fault Trough** – a valley formed by repeated movement and fracturing of rock within the fault zone.
  - **Sags** – small depressions where rock settled with in the fault zone – may fill with water to develop “Sag Ponds”
  - **Offset stream** –a stream flowing across the fault that is displaced by periodic fault movement or diverted when a shutter ridge is faulted in front of the of the drainage channel.

Landform from Strike-slip Faults



Earthquakes

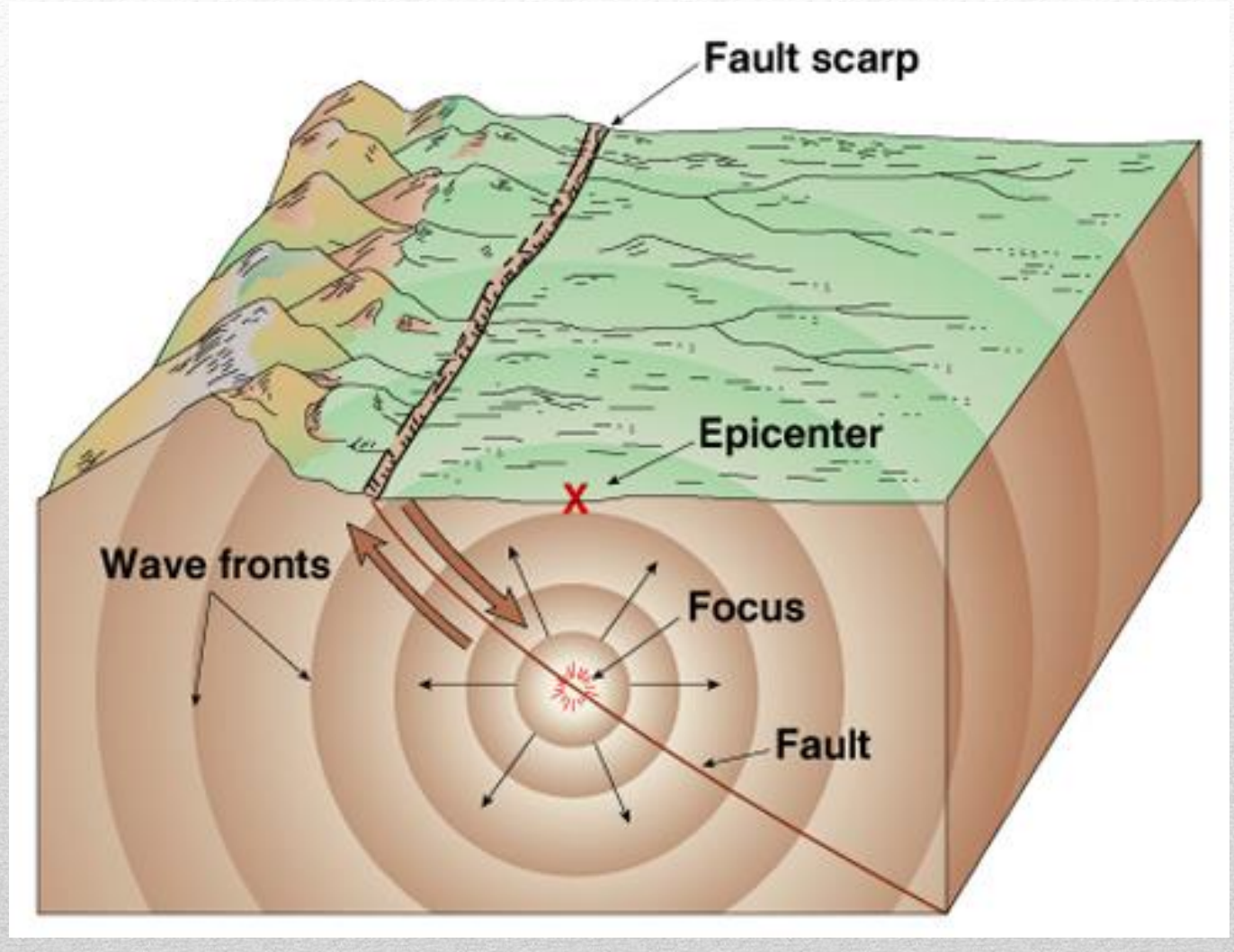
- A **vibration in the Earth produced by shock waves resulting from a sudden displacement along a fault**.
- Earthquakes may also **develop from the movement of magma or sudden ground subsidence**.
- **Fault movement allows an abrupt release of energy, usually after a long, slow accumulation of strain**
- **Fault rupture can take place at the surface and displacement can take place at considerable depth**

Earthquake Waves

- **Focus – or the epicenter of the earthquake.** (Waves move out from the epicenter like waves in water when rock thrown in)
  - **P Waves** – move through the Earth like sound waves alternately compressing and relaxing the medium that they pass through (like a slinky)
  - **S Waves**– strong side-to-side, up and down slowing moving waves.
  - **Both P waves and S waves** are "body wave"
  - **Surface waves** arrive immediately after the S waves and produce strong side-to-side movement as well as the up-and-down "rolling" motion.

52cd_SeismicWave_SP.swf

Earthquakes



Earthquake Magnitude

- **<u>Magnitude</u> –<u>the relative amount of energy released during an earthquake</u>**
  - Calculated on a logarithmic scale
  - Each difference in scale 32 times more intense than the previous.
    - 32 times more energy is released
  - Magnitude scale developed by Charles Richter
  - Used recently “moment magnitude”
  - Used more to describe the very large earthquake
- **Shaking intensity**– intensity scale devised by Giuseppe Mercalli in 1902
  - Updated to the **Modified Mercalli intensity scale**

Earthquake Hazards

- **Most damage from ground shaking**
- **Liquefaction– shaking of water-saturated material**. Turns to fluid resulting in subsidence, fracturing, and horizontal sliding of the ground surface.
- **Landslides triggered by the earthquake**
- **Tsunamis**– seismic sea waves caused by undersea earthquakes or landslides

86cd_Tsunami.swf